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FLAME TEST FOR MEDICAL UNIT, SELF-CONTAINED TRANSPORTABLE (INFLATABLE SHELTER ASSEMBLY)

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MUST (Medical Unit, Self-Contained Transportable) Shelters, supplied by three different manufacturers, were exposed to common hospital flame hazards, such as, trash fires, lighted cigarettes, alcohol spills, and burning wastepaper baskets. In addition to the field tests, undamaged specimens of each major component of each of the three manufacturer's shelters were subjected to standard laboratory tests. Gas samples were also collected during the field

tests and analyzed in the laboratory to identify the combustible products of the shelters and their levels.

The Field Test showed no significant differences in the overall response of the three different shelters to the fire hazards experienced in this study. The MUST Shelters tested were found to be vulnerable to external fires, particularly those fires originating along the inflated sides, which caused a rapid collapse of the shelter. The shelters were also vulnerable to internal fires, but prompt action by alert personnel can quickly control them, since interior shelter skins did possess a degree of flame-resistance. However, smoke generated by internal fires pose a serious problem to personnel inside the shelter.

None of the current, standard, laboratory test methods are suitable for predicting the net response of the composite structures. Although the laboratory tests indicated some differences in the response of specific components, the field studies indicated that the length of time to ignite and collapse of the shelters did not differ significantly between manufacturers.

The analysis of the collected gas samples revealed that no toxic products were found among the combustion products of floor samples.

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PREFACE

During a training exercise at Ft. Riley, Kansas, two smoke grenades were detonated which set fire to dry grass, ultimately burning approximately five acres of fields and destroying three (Medical Unit, Self-Contained, Transportable) hospital shelters. Since fire-resistant fabrics are used in these shelters, it was agreed by representatives of U.S. Army Troop Support Command, Office of the Surgeon General, and U.S. Army Natick Research and Development Command that personnel of the Materials Application Division, Clothing, Equipment and Materials Engineering Laboratory, NARADCOM would conduct field studies to determine the vulnerability of MUST Shelters to various fire threats. Accordingly, six shelters, two from each of three manufacturers were obtained by personnel of Aero-Mechanic Engineering Laboratory, NARADCOM and erected at Sudbury Annex. Comprehensive fire and smoke hazard studies were conducted during November 1975 by personnel of CEMEL and AMEL. Upon completion of the field tests, samples of each component and of the multi-layered floor and end panels were removed from the shelters' remains and subjected to further laboratory flammability studies. This report presents the results of both field and laboratory studies.

ACKNOWLEDGEMENT

A study of this scope could not have been successfully completed without the assistance of many individuals and organizations. The authors are indebted to Mr. Donald Shaw and Mr. Renzo Monti (deceased) Aero-Mechanic Engineering Laboratory (AMEL), NARADCOM for their administrative, logistical, and technical assistance during both the planning stage and the conduct of the test; also to Mr. John Lupien (AMEL) for making many of the physical measurements during the field test. In addition, we wish to acknowledge the cooperation and support of the Ft. Devens Fire Department during this exercise, and the contribution made be Mr. Frederick Meers and Mr. Richard Yeager, Photography Laboratory, NARADCOM.

FLAME TEST FOR MEDICAL UNIT, SELF-CONTAINED TRANSPORTABLE

(INFLATABLE SHELTER ASSEMBLY)

I. BACKGROUND AND INTRODUCTION

This report presents the results of fire tests conducted on Medical Unit, Self-Contained Transportable Shelters at the Fire Pit at the Maynard Test Facility, Hudson Road, Maynard MA 01754. This facility is an annex to the U.S. Army Natick Research and Development Command, Natick MA 01701. The tests were performed during the period 10 to 19 November 1975.

The purpose of these tests was to determine whether MUST Shelter assemblies incorporating end panels with enhanced fire resistance will ignite and burn when their exterior walls are contacted by a common flame hazard such as a trash fire, and whether their interior walls or floor will ignite and burn when contacted with common interior fire hazards such as, lighted cigarettes, alcohol spills, and a burning wastepaper basket. In addition, air and gas samples were collected and analyzed in the laboratory to identify the combustion products of the structure and their levels. Six MUST Shelters were tested, two from each of three manufacturers. In general, the test procedures followed were similar to those used in 1967 and 1968 by the Airesearch Mfg. Co. of Arizona[1], while under contract to the Department of the Army and the Office of The Surgeon General. However, additional tests were performed in order to gain insight into the size of fires which would ignite or collapse the shelters; to study the ease with which the fires, once started, could be extinguished; and to provide guidance as to the magnitude of laboratory tests required to simulate field situations.

End panels made by the following suppliers were tested:

a. Air Cruiser Co. items treated to meet the self-extinguishing requirements of ASTM D-1692.[2]

b. Firestone Co. items treated as in a above.

[1] Airesearch Mfg. Co. of Arizona, Engineering Report, Flame and Toxicity Test, Inflated Shelter, Task 10, Contract DA-49-193-MD-2908, 1967.

[2] ASTM, D-1692-59T, TENTATIVE Method of Test for Flammability of Plastics, Foams and Sheeting, Part 35.

c. Inflated Products Co. items designed to meet the more stringent flame-resistant requirements of Method 5905 or Federal Test Method Std. No. 191.[3]

Prior testing in 1967 showed that the polyurethane foam used as an insulating material in the Assembly End Panels and Air Ducts of the MUST Shelter contributed significantly to the rapid spread of fire originating at ground level against the Assembly End Panels. A major cause for this threat was considered to be the lack of a fire retardant material incorporated in the foam or applied as an additive finish to the foam.

In early 1968 a second test was conducted using Assembly End Panels containing polyurethane foam treated with a water soluble flame retardant. Using the same type of exterior fire, two panels gave mixed results. In the first panel, the polyurethane foam gave no evidence of decomposition or flame spread. In the second panel, the shelter materials ignited and burned in a vertical direction above the flame source. The burning rate was reported to have been much slower than that experienced with the shelter tested in 1967. Further, there was only slight evidence of horizontal flame travel. It was concluded from these results and observations that the rate of flame spread in the Assembly End Panel had been markedly reduced by the fire retardant treatment on the foam.

Action was subsequently taken to require by specification modification that a nondurable fire retardant be applied to the foam in the Assembly End Panel. At a later date, further improvement in the specification was made.[4] This required the use of a durable flame retardant in the foam to provide resistance of the effects of heat and water.

II. MATERIAL AND EQUIPMENT USED

A. SHELTER AND COMPONENTS

The units tested consisted of a one-section assembly with end panels. The shelters were unequipped. Two shelters and associated

[3] Method 5905, Flame Resistance of Material; High Heat Flux Flame Contact, of Federal Test Method Std. No. 191.

[4] Military Specification, MIL-S-43869A(GL), Shelter, Inflatable with Airlock and Connector, Corridor, Inflatable (MUST), 8 May 1974.

components from each of three different manufacturers were used in the flame tests as follows:

Components used	Parts Number Air Cruisers	Firestone Coated Fabrics	Inflated Fabrics
2 Inflatable Section Assemblies	889139	5-4-1380	5-4-1264-1
4 End Panel Assemblies	889138	5-4-1373	5-4-1275
2 Plenum Assemblies, Inflated Section	694475	5-4-1409	5-4-1267
2 Air-Conditioning Ducts	697941-3	5-4-2114	5-4-2114
2 Floor Assembly Sections	889429	5-4-1410	5-4-1270

Utility Power Pack and its associated components.

Fuel Supply

B. TEST EQUIPMENT

The equipment listed below was required to conduct the various tests and analyses.

Item	Quantity Required
Test site layout	-
Fire fighting equipment	-
Photo coverage - 16 mm color movies and still photographs were taken of the tests.	-
Shredded paper	150 pounds
Propane torch	1
Isopropyl alcohol	6 pints
Metal wastebasket	1
Evacuated glass bottles	-
Raman Spectrometer	-
Infra-Red Spectrometer	-

III. TEST LAYOUT AND CONDITIONS

The tests were conducted to simulate both internal and external fires. The shelters used were separated a sufficient distance to prevent damage to any other shelter while any test was in progress. The shelters were erected and tested in the following sequence (see Figure 1).

FIGURE 1. Sequence of Tests

5	4	3
6	2	1

1 and 3, Inflated Products Co.
2 and 4, Firestone Coated Fabrics Co.
5 and 6, Air Cruiser Co.

A. TEST CONDITIONS OF SHELTERS FOR INTERNAL FIRES

The inflatable shelter, with two end panels installed, was connected through an air duct to a Utility Element which supplied recirculated air through the test unit and bleed air for inflating the cells. The airflow was throttled in such a manner that a flow of approximately 400 cfm of air (.19 m^3/s) was moving into the shelter. The shelter section was erected to a gage pressure of approximately 1.5 psi (10.3×10^3 Pa) and was pressurized internally to 0.2 to 0.4 inches of water (49.8 to 99.6 Pa). The Utility Element was positioned a safe distance from the test unit with added lengths of ducting and cabling as required (see Figure 2). The fuel supply was located approximately 200 feet (61 m) from the test unit.

B. TEST CONDITIONS OF SHELTERS FOR EXTERNAL FIRES

The Inflatable Shelter was erected and two end panels installed with an air-conditioning duct as described in paragraph III-A. The unit was pressurized internally to 49.8 to 99.6 Pa, and six cells were pressurized at approximately 0.75 psi, (5.2×10^3 Pa) and six cells at approximately 1.5 psi (10.3×10^3 Pa).

IV. FIELD TEST PROCEDURES AND RESULTS

The following fire tests were conducted on the MUST Shelters and the results are summarized in Tables 1 and 2. Gas samples were collected and analyzed in the laboratory.

A. INTERNAL FIRE TESTS

1. Cigarette test. All six shelters were subjected to the cigarette test. Four lighted cigarettes were placed on the floor of the MUST Shelter and allowed to burn to the end (see Figure 3). The cigarettes charred the floor without any flaming.

2. Torch test. All six shelters were subjected to the torch test. The air-conditioning distribution plenum was subjected to the flame of a propane torch for 10 seconds (see Figure 4). The coated fabric melted, with slight charring, but did not ignite.

3. Alcohol Spill test. All shelters were subjected to this test. One pint ($4.7 \times 10^{-4} M^3$) of isopropyl alcohol was poured in approximately the center of the floor and ignited (see Figure 5). A yellow flame appeared immediately upon ignition. Approximately 30 seconds

after ignition, dense black smoke was produced (see Figure 6) and increased in density (see Figures 7 and 8) so that the shelter was usually evacuated by test personnel within 60 seconds of ignition. The fire did not spread rapidly during the test, but in general contained itself to an area of 3 feet (.915 m) in diameter (see Figure 9) and appeared to be self-extinguishing. The residual fire was easily extinguished with a carbon-dioxide fire extinguisher.

4. Newspaper test. Two pounds (.9 kg) of shredded newspaper was placed in a metal wastepaper basket and one pound (.45 kg) of shredded newspaper was scattered on the floor around the basket. In shelters 1, 2, and 6, the basket was positioned in the corner against an end panel and the shelter inner wall, and the shredded paper ignited (see Figure 10). Shortly after ignition (between 20 and 25 seconds), one of the inflated cells ruptured, scattering the flaming newspaper about the tent and propelling the wastepaper basket several feet across the room (see Figures 11, 12, and 13). The scattered paper burned out quickly. The newspaper in the basket continued to burn for as long as 10 minutes. In the other tests in shelters 1, 2, and 5, the basket was placed near the window along an end panel. The shredded newspaper in the basket and around the basket was ignited. In approximately one and one half minutes after ignition the shelters began to fill with smoke. Flames penetrated through the end panel in two and one-quarter to two and one-half minutes after the basket was ignited.

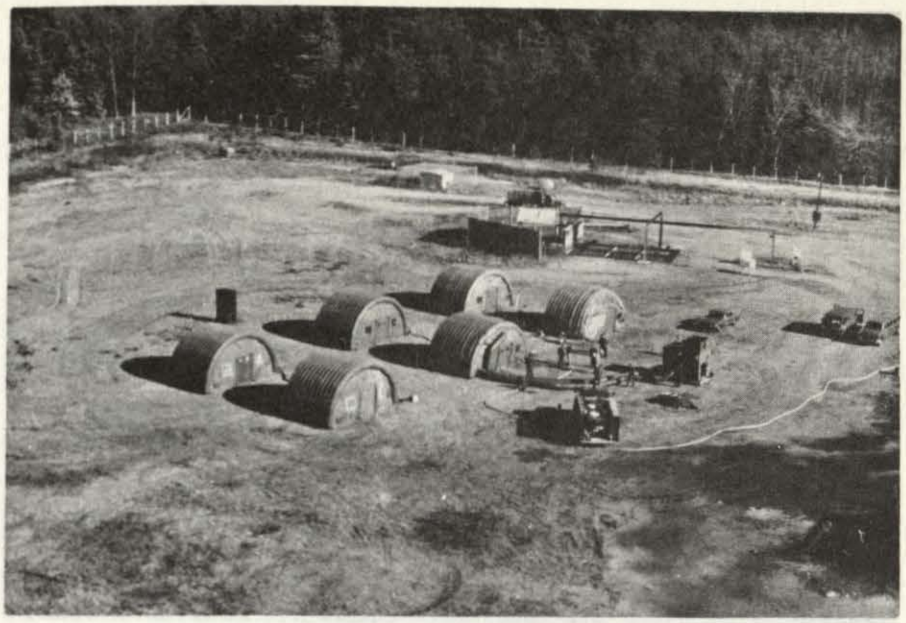


Figure 2. MUST Shelters at Sudbury Annex

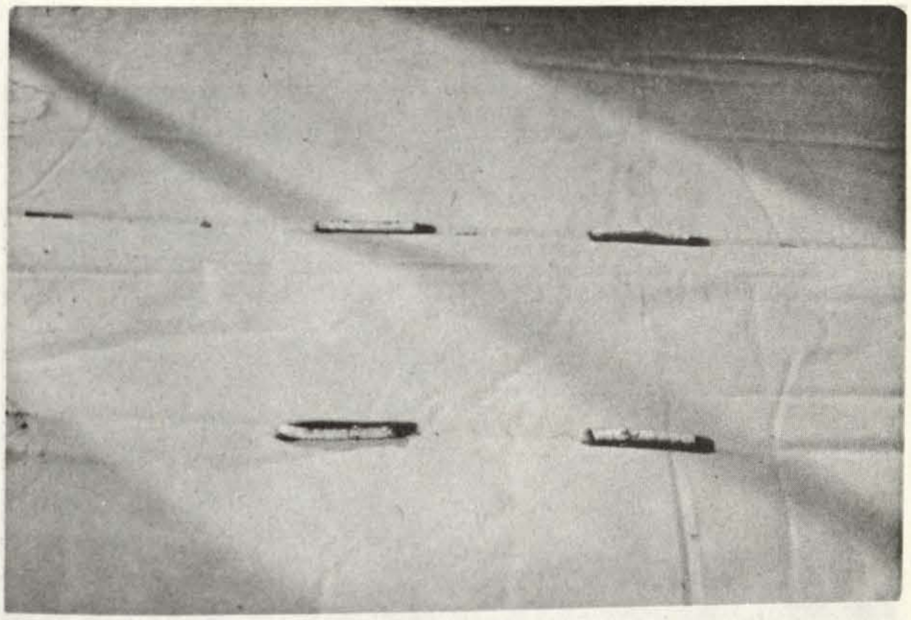


Figure 3. Effects of Lighted Cigarettes on MUST Shelter Floors

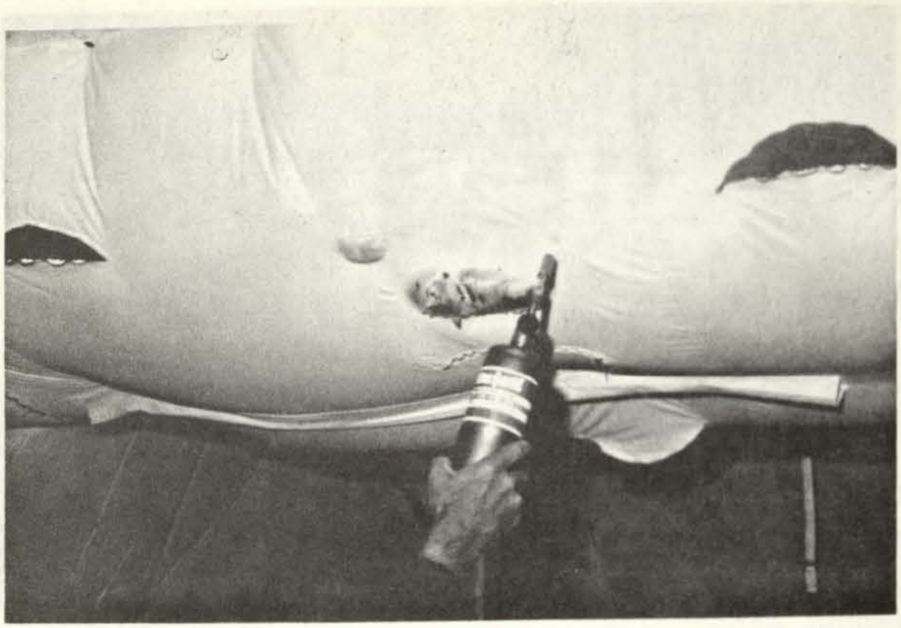


Figure 4. Effects of a Propane Torch on the Air Distribution Plenum.

Figure 5. Effect of a Spilled Alcohol Fire, Immediately After Ignition.

Figure 6. Effect of an Alcohol Fire, 30 Seconds After Ignition.

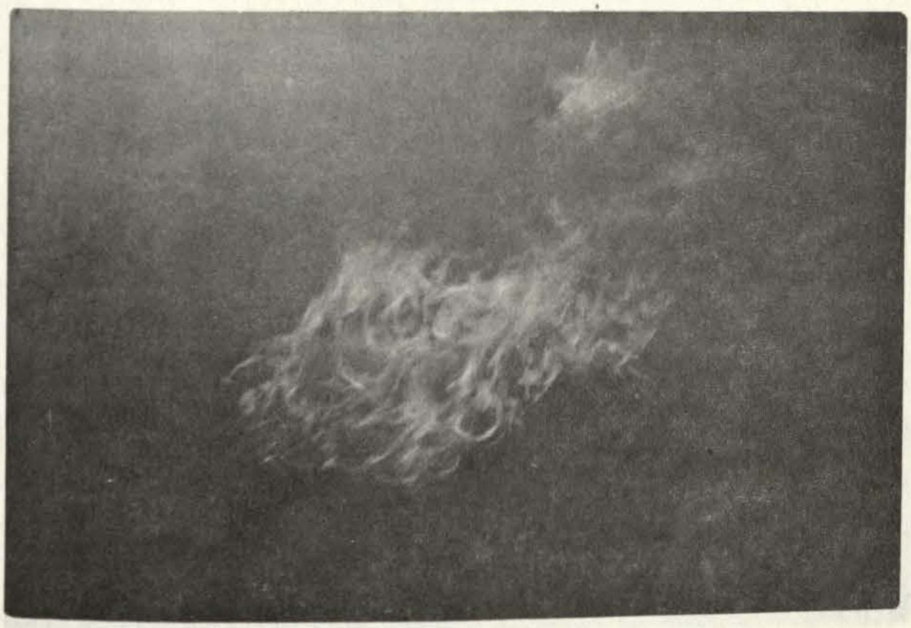


Figure 7. Effect of an Alcohol Fire, 45 Seconds After Ignition.

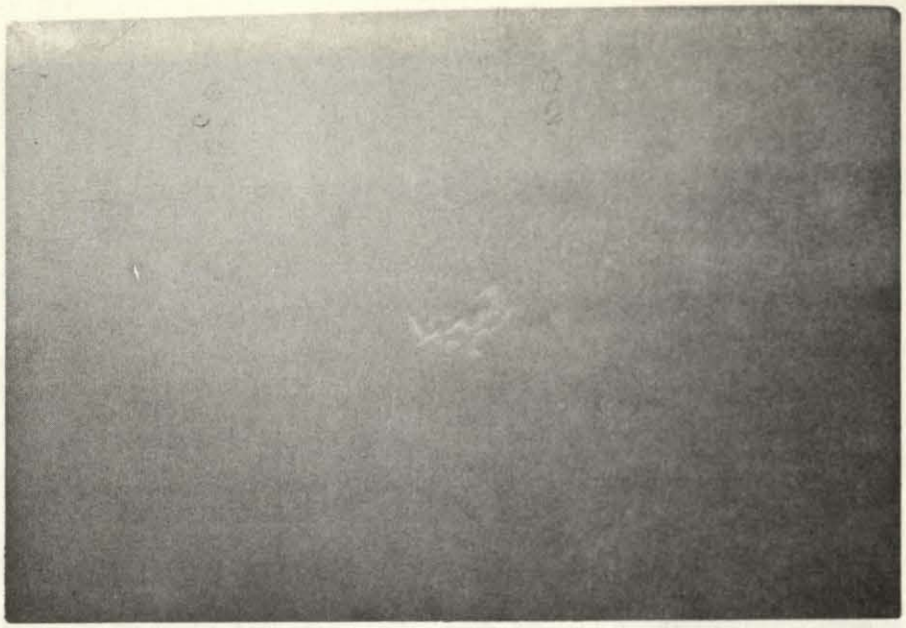


Figure 8. Alcohol Test 60 Seconds After Ignition.
(Note decrease in visibility)

Figure 9. Damage to the Floor Caused by the Alcohol Test.

Figure 10. Effect of an Interior Wastebasket Fire. (Note ruptured inner side wall)

Figure 11. Effect of an Interior Wastebasket Fire, 25 Seconds After Ignition (Note bladder has exploded, scattering burning debris)

Figure 12. Effect of Interior Wastebasket Fire, 25 Seconds After Ignition, Debris Scattered to Opposite Side of Shelter.

Figure 13. Effect of Interior Wastebasket Fire, Several Minutes After Ignition.
(Note debris on the floor has self-extinguished)

B. EXTERNAL FIRE TESTS

The external fire test consisted of shredded newspaper being placed in contact with the exterior end panel or in contact with the side of the inflated section. The newspaper was spread two pounds (.9 kg) per linear foot (.305 m) of contact.

1. Exterior Fire No. 1. (Standard Test) Six pounds (2.7 kg) of shredded newspaper were placed along the outside of, and in contact with, an end panel and ignited. Shelters 3, 4, and 5 were tested in this manner. The shelters ignited, with self-sustaining flames, within 20 to 25 seconds (see Figure 14). In general, the fire produced a hole in the shelters within 30 to 60 seconds after ignition of the paper (see Figures 15 and 16). An inflated cell ruptured in shelter 4 two and one-half minutes after ignition of the paper. The fire in all the shelters was extinguished within three minutes of ignition of the paper in order to save the shelters for additional tests. The fires were easily extinguished with water.

2. Exterior Fire No. 2. In an attempt to simulate a catastrophic external fire, 26 pounds (11.7 kg) of shredded newspaper was placed along the outside of the inflated cells and ignited. Shelters 3, 4, and 5 were used for this test. The first cell in each of the shelters exploded in 13 to 20 seconds after ignition of the paper (see Figure 17). Within 30 to 40 seconds the shelter ignited with self-sustaining flames (see Figure 18). Shelter 4 collapsed within 50 seconds after ignition of the paper. Shelter 5 collapsed in 2 minutes (see Figure 19), and Shelter 3 within 3 minutes and 35 seconds. Figure 20 depicts the typical damage caused to the MUST shelters by large external fires.

3. Exterior Fire No. 3. Similarly, in order to simulate a large external fire at the end panels, twelve pounds (5.4 kg) of shredded newspaper was placed along the outside of a panel. Shelters 1, 2, and 6 were used for this test. The shelters were ignited with self-sustaining flames 20 to 30 seconds after the ignition of the paper (see Figure 21). With shelters 1 and 6, an end cell exploded 30 seconds after the ignition of the paper. A number of cells ruptured in all the shelters within two to two and one-half minutes after the ignition of the paper (see Figure 22). Shelter 1 was allowed to burn unchecked and the shelter collapsed three minutes after the ignition of the paper. Figure 23 depicts the typical

damage caused to an end panel by this type of fire (Shelter 6).

4. Detailed observations made during the tests are given in Tables 1 and 2.

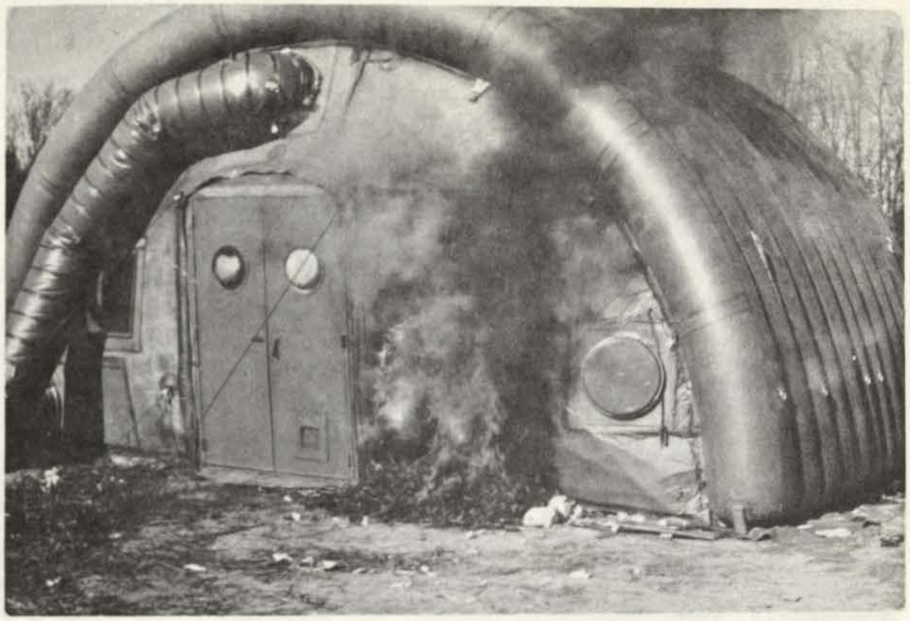


Figure 14. Exterior Fire 1, 6 lbs. of Shredded Newspaper Approximately 45 Seconds After Ignition.

Figure 15. Exterior Fire No. 1, Approximately 75 Seconds After Ignition.

Figure 16. Damage Caused by Exterior Fire No. 1 (Fire Extinguished by H_2O)

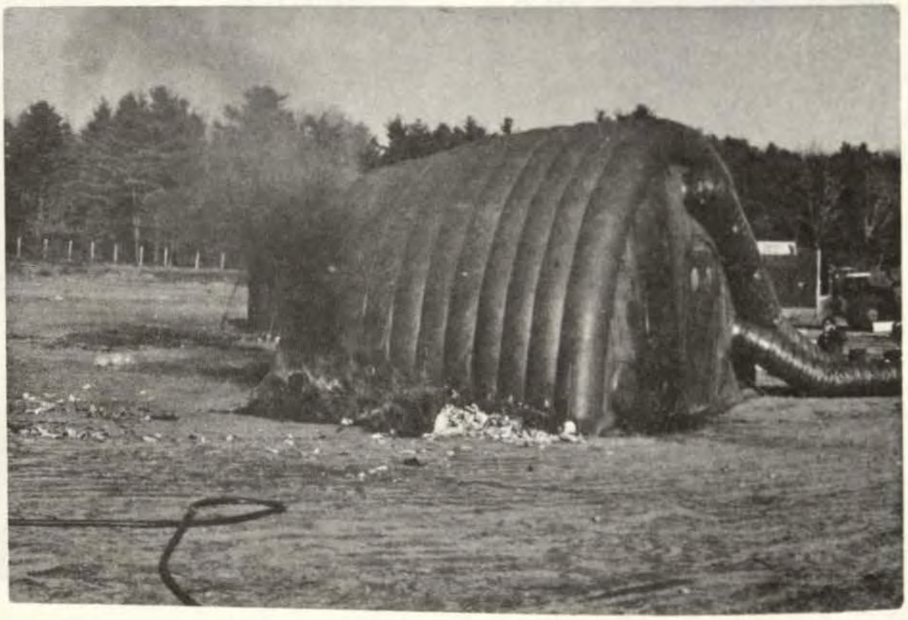


Figure 17. Exterior Fire, No. 2, Approximately 30 Seconds After Ignition 26 lbs. of Shredded Newspaper Along the Inflated Tubes

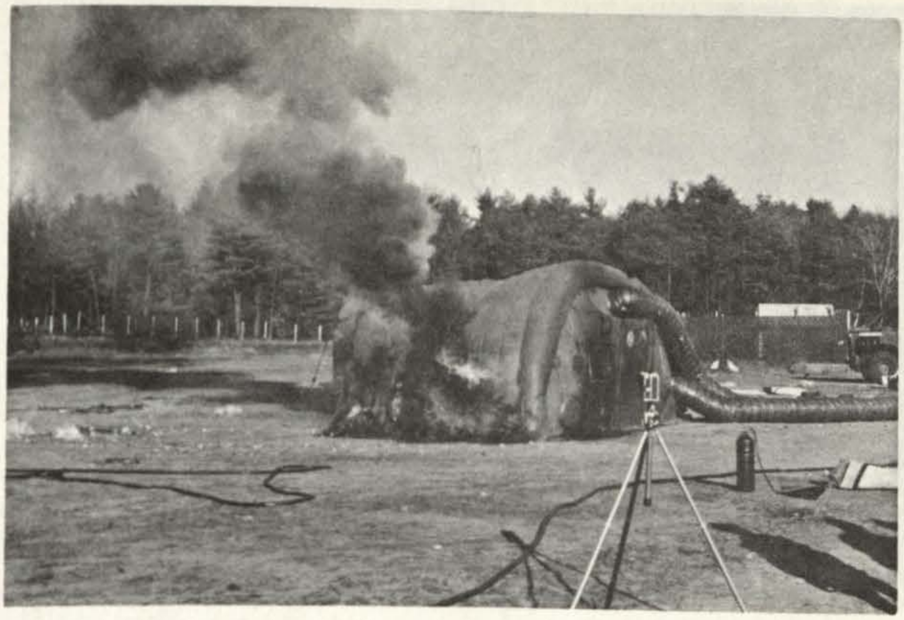


Figure 18. Exterior Fire No. 2, Approximately 50 Seconds After Ignition.

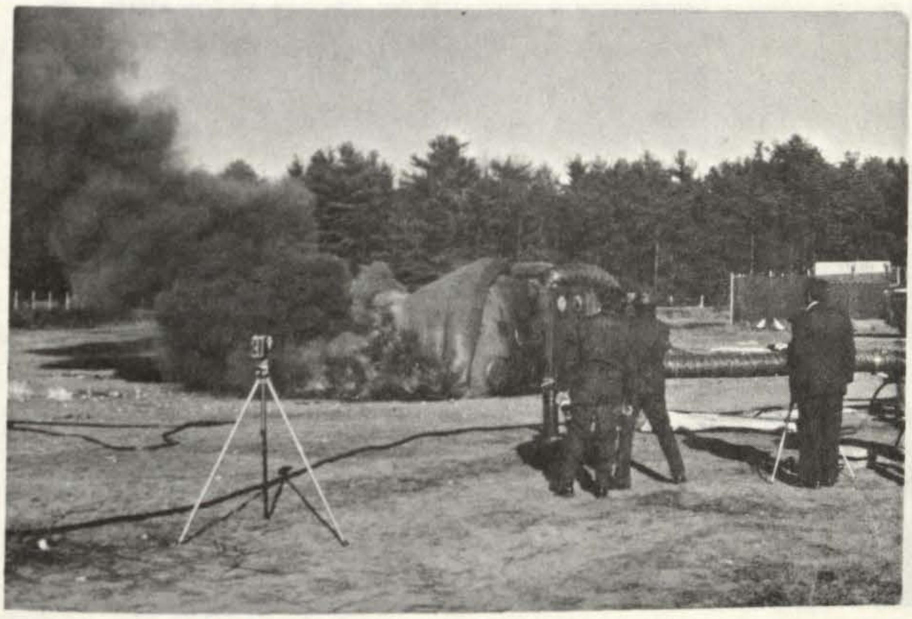


Figure 19. Exterior Fire No. 2, Approximately 2 Minutes After Ignition.

Figure 20. Damage Caused by Exterior Fire No. 2.

Figure 21. Exterior Fire No. 3, 12 lbs of Shredded Newspaper, several Seconds After Ignition.

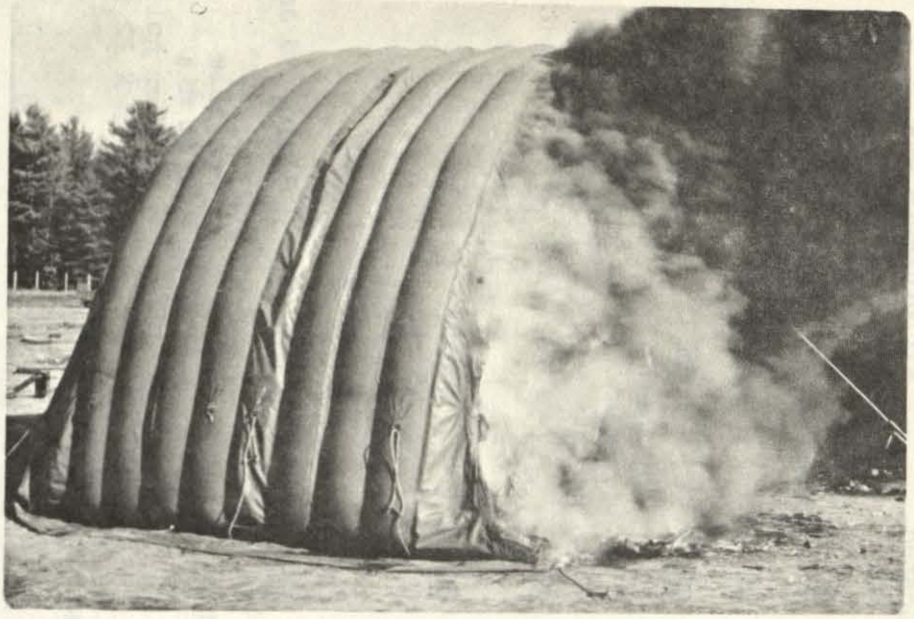


Figure 22. Exterior Fire No. 3, Approximately 2 Minutes After Ignition.

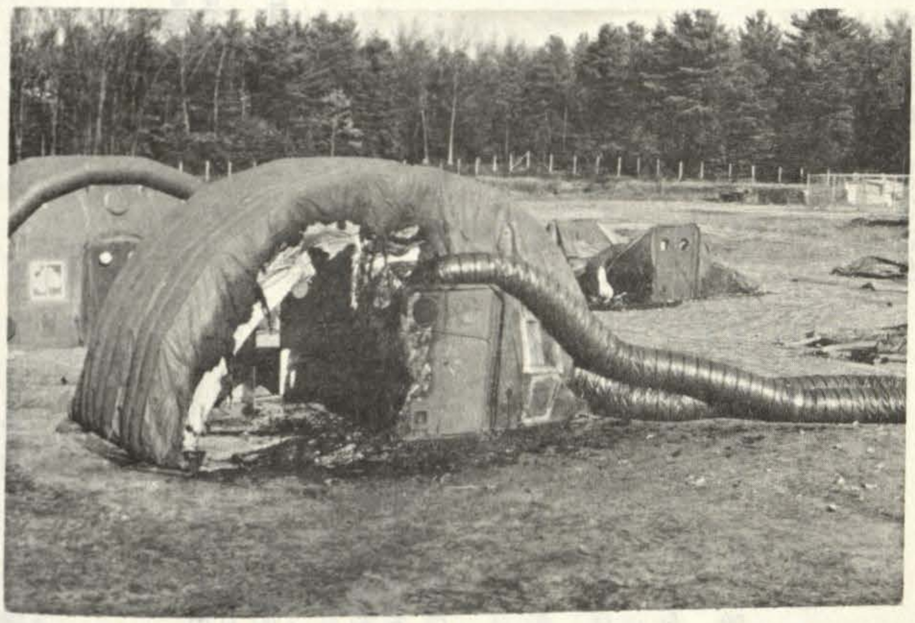


Figure 23. Damage Caused by Exterior Fire No. 3.
(Fire Extinguished by Water)

TABLE 1. INTERIOR FIRE TESTS CONDUCTED ON MUST SHELTERS

Type of Tests	Shelter No.					
	Inflated Products Co.		Firestone Coated Fabrics Co.		Air Cruisers Co.	
	1	3	2	4	5	6
Cigarette Test	OK	OK	OK	OK	OK	OK
Torch Test (Plenum)	OK	OK	OK	OK	OK	OK
Alcohol Spill Test						
Black smoke begins, seconds	30	35	25	30	20	30
Dense smoke forced personnel to leave shelter	60 sec.	-	60 sec.	50 sec.	1 min, 45 secs Gas Mask Worn	-
Fire out	-	6 min.	2 min.	10 min.	3 min.	3 min, 58 sec
Burn area	-	3 feet in diameter	3 feet in diameter	-	-	one hole 1 ft dia another hole 30 in X 12 in
Newspaper Test (Metal wastepaper basket placed in corner of shelter)						
Cell exploded	shortly	-	20	-	-	25

TABLE 1. INTERIOR FIRE TESTS CONDUCTED ON MUST SHELTERS (CONT.)

Type of Tests	Shelter No. Inflated Products Co. 1	3	Firestone Coated Fabrics Co. 2	4	Air Cruisers Co. 5	6
Fire extinguished	10 min.	-	-	-	-	2 min, 05 sec.
Newspaper Test (Metal wastepaper basket placed near the window along end assembly panel.)						
Shelter burning on its own	30 sec.	-	-	-	-	-
Forced to leave shelter	1 min. 15 sec.	-	1 min.	-	1 min. 40 sec.	-
Severe dense smoke	1 min. 30 sec.	-	2 min.	-	-	-
Flames burned	2 min. 15 sec.	-	2 min. 30 sec.	-	appeared to be self-extinguishing	-
Fire extinguished	-	-	-	-	3 min. 10 sec.	-

TABLE 2. EXTERIOR FIRE TESTS CONDUCTED ON MUST SHELTERS

Type of Test	Shelter No.					
	Inflated Products Co.		Firestone Coated Fabrics Co.		Air Cruisers Co.	
	1	3	2	4	5	6
Newspaper Test (6 pounds shredded newspaper placed along the outside of the end panel.)						
Shelter ignited	-	25 sec.	-	20 sec.	25 sec.	-
Hole burned in shelter	-	45 sec.	-	30 sec.	1 min.	-
Corner cell exploded	-	-	-	2 min. 25 sec.	-	-
Fire extinguished	-	2 min. 35 sec.	-	2 min. 45 sec.	1 min. 50 sec.	-
Newspaper Test (12 pounds of shredded newspaper placed along the outside of the end panel.)						
Shelter ignited	28 sec.	-	30 sec.	-	-	20 sec.
Hole burned in shelter	40 sec.	-	50 sec.	-	-	25 sec.
Corner cell exploded	30 sec.	-	-	-	-	30 sec.

TABLE 2. EXTERIOR FIRE TESTS CONDUCTED ON MUST SHELTERS (CONT.)

Type of Test	Shelter No. Inflated Products Co. 1	Inflated Products Co. 3	Firestone Coated Fabrics Co. 2	Firestone Coated Fabrics Co. 4	Air Cruisers Co. 5	Air Cruisers Co. 6
Multiple cells exploded	2 min. 30 sec.	–	2 min.	–	–	2 min. 25 sec.
Complete collapse	3 min.	–	–	–	–	–
Fire extinguished	3 min. 30 sec.	–	–	–	–	5 min. 25 sec.
Newspaper Test (26 pounds of shredded news-paper placed along the out-side of the inflated section side.)						
Shelter ignited	–	40 sec.	–	35 sec.	30 sec.	–
1st cell exploded	–	20 sec.	–	13 sec.	13 sec.	–
2nd cell exploded	–	35 sec.	–	20 sec.	23 sec.	–
3rd cell exploded	–	–	–	–	35 sec.	–
Back collapsed	–	1 min. 15 sec.	–	–	50 sec.	–
Complete collapse	–	3 min, 35 sec.	–	50 sec.	2 min.	–
Fire extinguised	–	4 min.	–	1 min, 30 sec.	2 min, 30 sec.	–

C. PRESSURE AND TEMPERATURE MEASUREMENTS

Pressure within the inflated cells and shelters and temperatures inside the shelters were monitored during all fire tests. The temperature was obtained approximately in the center of the shelter and at a height of five feet above the floor. Results show that there was no appreciable increase in cell pressure during either the external or internal fires. This indicated that the cells of the shelter ruptured due to breakdown of the fabric rather than an increase in pressure. The results also indicated that, for external fires, there was no appreciable temperature rise inside the shelters. Obviously, there was a marked increase in temperature for internal fires. In many instances, the fires were started directly underneath or very near the thermocouple.

V. DISCUSSION OF FIELD TEST RESULTS

The results of the exterior fire tests show that the MUST Shelters ignited and burned when their exterior walls were contacted by a common flame hazard, such as a trash fire, simulated in this test by use of shredded newspaper. The point at which the exterior fire started was critical to the length of time the shelter remained upright. If the fire originated along the side of the shelter, rupture of the bladder, or cell, occured within 13 seconds, and the collapse of the shelter occurred as quickly as 50 seconds (see Table 2). This type of fire would leave very little time for evacuating personnel. If the fire started along the end panel, more time for action was available from 3 to 5 minutes. It was noted that, during these exterior fires, the interior of the shelters remained relatively smoke-free, and the temperature inside the shelters remained constant or increased only a few degrees. This absence of smoke and heat indicated that it would be possible for a fire to be well developed before personnel inside the shelter became aware of the danger. However, the newspaper fires were easily extinguished with water.

The results of the interior fire tests show that lighted cigarettes were no threat to the MUST Shelters. The cigarettes burned out with some slight charring to the floor. The torch test indicated that plenum fabric, with air blowing through, melted and formed a hole when subjected to the propane torch. The plenum fabric showed signs of charring but no ignition, due to the outrushing air dissipating combustible products. However, this

same fabric will burn readily when not inflated.

The alcohol test showed that, for internal fires, smoke may be a greater hazard to the safety of personnel inside the shelter than the fire itself. When the alcohol was poured on the floor and ignited, the fire did not spread and was limited to the area of spillage. The fire continued to burn until the alcohol was consumed and had a tendency to go out unless fanned by a draft. The fire was easily extinguished with a carbon dioxide extinguisher. A fire blanket would probably have been just as effective. However, when the alcohol fire was allowed to persist, a dense black smoke began to form at approximately 30 seconds after ignition, and within a minute, the shelter was filled with smoke and had to be evacuated.

The wastepaper basket tests showed that in those tests where the wastepaper basket was positioned in a corner against the shelter, approximately 25 seconds after ignition of the paper one of the inflated cells would rupture, scattering the flaming newspaper throughout the shelter and propelling the wastepaper basket several feet across the room. When totally unexpected, it was a startling experience. The scattered paper burned out quickly and the fire in the wastepaper basket was easily extinguished. The damage to the cell was severe enough to require more than a "field repair".

In those instances where the wastepaper basket was placed in close proximity to an end panel, upon ignition, the paper would burn and the shelter would fill with smoke in approximately one and one-half minutes. If the basket was within two feet of an end panel, the flames would attack the end panel and burn through in about two and one-half minutes. In those tests where the wastepaper basket was placed a yard or more from an end panel, the flames did not make contact with the wall, no ignition occurred, and the fire in and around the wastebasket was easily controlled.

The results showed that there was no marked difference in the response of the shelters manufactured by three different suppliers, when exposed to various exterior and interior fire hazards mentioned in this report. All the shelters appeared to ignite and burn in a similar manner and at about the same rate.

VI. CONCLUSIONS BASED ON FIELD OBSERVATIONS

1. The MUST Shelters tested were found to be extremely vulnerable to extensive external fires.

2. The greatest danger from an external fire came from the rapid collapse of the shelter when the fire originated along the inflated side of the shelter.

3. The MUST Shelters were less vulnerable to internal fires. Since the shelters are usually manned, internal fires can generally be detected quickly and prompt action taken to extinguish them.

4. Lighted cigarettes dropped on the floor appeared to pose no serious threat.

5. The plenum fabric, with air flowing through it, did not appear to pose a threat when directly contacted by a flame.

6. The smoke generated by an interior fire, particularly from the coated fabrics and polyurethane foam, could possibly create confusion within the shelter, although this risk is hard to judge from observations being made within one section of what would normally be a multisection assembly. In general, the smoke was most dense five to six feet above the floor, and was cleared within two to three minutes by the shelter's exhaust system.

7. Wastebaskets should not be placed in a corner or within two feet of a wall.

8. There appeared to be no major differences in the overall response of the three manufacturers' shelters to the fire hazards experienced in this study.

VII. LABORATORY FLAME TESTS OF MATERIALS USED IN THE SHELTERS

In order to provide additional insights into the inherent fire-resistance of component parts, and provide guidance as to the rigor with which existing laboratory methods will predict behavior in field situations, undamaged specimens of each major component of each of the three manufacturers' shelters were subjected to standard laboratory tests. Currently, two standard test methods are used to define the fire-resistance of those materials and components where fire-resistance is a stated requirement. These Methods 5903[5] and 5905 of Federal Test

[5]Method 5903 of Federal Test Method Standard No. 191.

Standard No. 191. Method 5903, the vertical Bunsen method, uses a flame with an energy output of approximately 1 cal/cm^2 sec (4.18 W/m^2). In order to pass, a sample 2 and 3/4 inches (7 X 10^{-2} m) by 12 inches (30.5 X 10^{-2} m) must not continue to burn for more than three seconds after being exposed to the vertical Bunsen for twelve seconds, and must have a char length of not more than 4.5 inches (11.4 X 10^{-2}m).

Method 5905 provides a more rigorous test, in that a Meeker burner with an energy output of 2.0 cal/cm^2 sec (8.36 W/m^2), is utilized. In this instance, the sample is exposed for twelve seconds, and continued flaming for more than two seconds constitutes failure. (Preliminary laboratory measurements of the energy available from free burning shredded newspaper indicated an energy output of approximately 1.6 cal/cm^2 sec (6.89 W/m^2)).

Of the three differently manufactured shelters studied, only the polyurethane foam insulation in those manufactured by Inflated Products Co., produced under the latest specification (MIL-S-43869A), have a requirement to meet the more rigorous conditions of Method 5905. For those shelters manufactured prior to the issuance of MIL-S-43869A (GL) the foam insulator was required to meet the less severe conditions of ASTM-D-1692-59T. All other components of the MUST shelter which have a requirement for flame resistance must meet the conditions of Method 5903.

VIII. BASIC MATERIALS USED IN THE SHELTER

Each MUST shelter is constructed from basic components or materials whose identification is given in Table 3, and whose arrangements into composite structures are diagrammed in Figures 24, 25 and 26.

Diagram of Inflated Side Walls with

Identification of Basic Materials. (Ref. Table 3)

Fig. 24 Inflated Side Walls

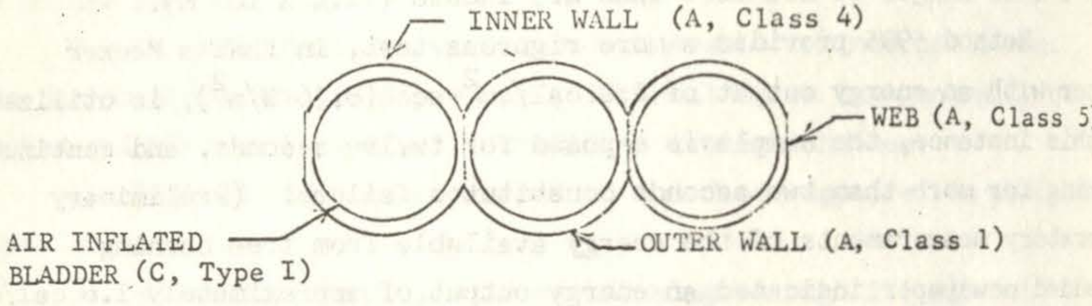


Fig. 25

End Panels

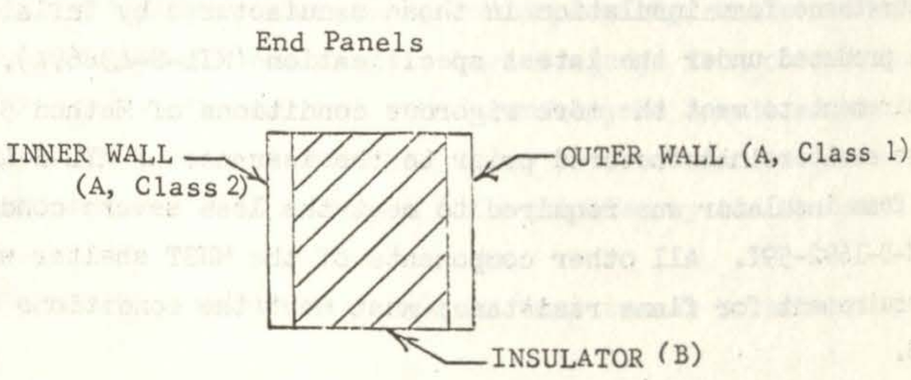


Fig. 26

Shelter Floor

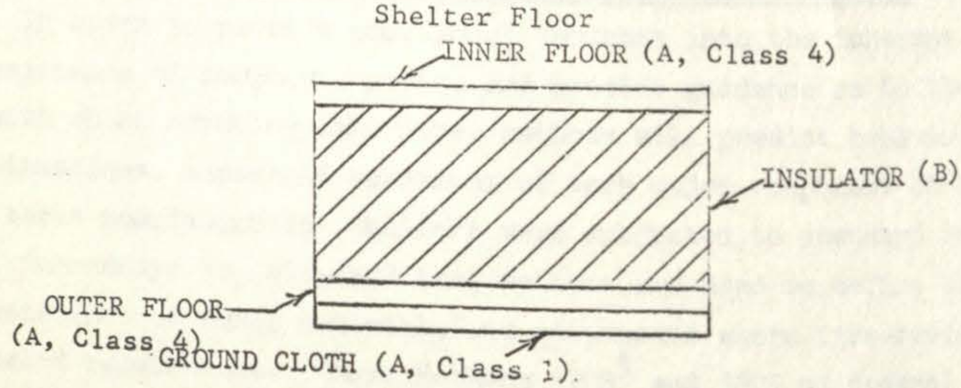


TABLE 3. DESCRIPTION OF MATERIALS USED IN SHELTER COMPONENTS

Material Designation	Description
A	Cloth, Polyester, Coated (Chloroprene Base Coated, Chlorosulphonated Polyethylene Top Coated), MIL-C-43285B, Type I. Classes 1 and 2, coated both sides, flame resistance required. Classes 4 and 5, uncoated back, no flame resistance required.
B	Foam, Polyurethane. 1. Air Cruiser - no flame resistance required. Development contract between Surgeon General and Industry. 2. Firestone - flame resistance required. LP-P-DES 42-70. 3. Inflated Products - flame resistance required. MIL-S-43869.
C	Cloth, Nylon, Coated, MIL-C-43808. Type I - Chloroprene coated, flame resistance required; used in bladder. Type II - Chlorosulphonated polyethylene coated, no flame resistance required; used in plenum.

A comparison of Figures 24, 25, and 26, and Table 3 shows that the exterior surfaces of the shelter and the interior surface of the end panels are polyester fabric, coated on both sides, and are required to meet a flame-resistance test, while the remaining inner surfaces are polyester fabrics coated on the exposed side only and are not required to be flame resistant.

IX. RESULTS OF LABORATORY FLAMMABILITY TESTS

The data, obtained in the laboratory with those materials for which there is a specific flame-resistance requirement, are given in Table 4. Additionally, measurements were also made on those components for which flame-resistance is inferred either through the coating used

on the base fabric, or in the case of the coated nylon used in the plenum; flame-resistance is inferred through the basic properties of the materials and their usage within the shelter. These are given in Table 5.

X. DISCUSSION OF LABORATORY FLAME TESTS

A. COMPONENTS WITH A FLAME-RESISTANCE REQUIREMENT

As indicated in Table 4, the majority of the components tested have a requirement to meet the conditions imposed by laboratory Method 5903, while only the foam manufactured under the latest specification is required to meet the conditions of Method 5905. The data in Table 4 indicated that the double-coated polyester fabric utilized in the Firestone and Inflated Products Co. shelters meets the requirements imposed by Method 5903, whereas the Air Cruiser product did not. However, the equivalent coated fabric used in the ground cloth supplied by all three manufacturers did meet the conditions of Method 5903. It is inferred from this comparative response, that the failure of this basic material in the Air Cruiser Shelter was due to excessive wear and possibly solar degradation. This conclusion is further supported by date of manufacture (1967) and the peeling and cracking of the coating observed on the outer walls of the two shelters. The other shelters studied had not been subjected to field use.

The data in Table 4 indicated that the basic polyurethane foam used in the Inflated Products Co. shelter was a distinct improvement in flame-resistance, as compared to the other shelters, although not meeting the requirements of Method 5905. Of the basic foams tested, the sample obtained from the Firestone Shelters burned most vigorously.

B. COMPONENTS WITH NO FLAME-RESISTANCE REQUIREMENT SPECIFIED

The data of Table 5 indicated that, except for the nylon coated fabric used in the bladders of the shelters, none of the other components show any significant fire resistance when tested by Methods 5903 or 5905. Similarly, the only foam composites showing a significant degree of fire resistance, when tested by Method 5905, was the manufactured under the latest specification MIL-S-43869A (GL).

TABLE 4

FLAMMABILITY MEASUREMENTS WITH COMPONENTS HAVING A REQUIREMENT OF MEETING METHOD 5903 OR 5905

Manufacturer	Component Description	Usage	Flammability Results				
			Method 5903*		Method 5905*		Method Required
			After Flame secs	Char Length Meter (m) X 10^{-2}	After Flame sec	% Consumed	
Air Cruiser	Double-Coated	Outer Wall	17.2	13.2	6.0	73	5903
Firestone	Polyester		0.0	7.6	7.0	67	5903
Inflated Products	(Item A)		1.6	6.6	8.0	80	5903
Air Cruiser	Double-Coated	Ground Cloth	0.0	9.9	7.0	48	5903
Firestone	Polyester		2.2	5.6	7.0	66	5903
Inflated Products	(Item A)		1.0	7.4	7.0	66	5903
Air Cruiser	Polyurethane Foam	Used in the End Panel and Floor			23.0		-
Firestone	(Item B)				38.0		-
Inflated Products					9.0		5905

*METHOD 5903: Not more than 3.0 secs after flame and a char length of not more than 11.4×10^{-2} m.
**METHOD 5905: Not more than 2.0 secs after flame.

TABLE 5

FLAMMABILITY MEASUREMENTS WITH COMPONENTS HAVING NO FLAMMABILITY REQUIREMENTS

Manufacturer	Component Description	Usage	Flammability Results			
			Method 5903		Method 5905	
			After Flame secs	Char Length Meters (m) X 10^{-2}	After Flame sec	% Consumed
Air Cruiser	Polyester Coated One Side	Web	84.0	18.3	17.0	100
Firestone			26.0	18.3	17.0	84
Inflated Products	(Item A)		134.0	27.7	13.6	100
Air Crusier	Polyester Coated One Side	Inner Wall and Floor	35.0	13.7	10.0	100
Firestone			85.0	21.0	12.0	100
Inflated Products	(Item A)		143.0	24.6	7.0	100
Air Cruiser	Nylon Coated One Side	Bladder	7.0	15.5	6.0	80
		Plenum	20.0	22.9	22.0	100
Firestone		Bladder	0.0	11.7	2.0	68
		Plenum	31.0	18.0	46.0	
Inflated	(Item C)	Bladder	0.0	10.4	2.2	
		Plenum	3.4	12.4	25.0	

TABLE 5 (CONT.)

FLAMMABILITY MEASUREMENTS WITH COMPONENTS HAVING NO FLAMMABILITY REQUIREMENTS

Manufacturer	Component Description	Usage	Flammability Results Method 5905	
			After Flame sec	% Consumed (Foam)
Air Cruiser	Foam Composite (with Covering Fabrics)	End Panels (approx. 1 inch thick)	285	100
Firestone			123	100
Inflated Products			13	less than 10%
Air Cruiser	Foam Composite (with Covering Fabrics)	Floor (approx. $\frac{1}{2}$ inch thick)	146	100
Firestone			152	100
Inflated Products			90	100

XI. CONCLUSIONS FROM LABORATORY FLAMMABILITY TESTS

1. Some of the items used within the shelter do not possess any significant degree of flame-resistance, and thus, as expected, were found to be very susceptible to fire and could be expected to burn vigorously when either rupture of the inner surface occurs or the shelter collapses and fire ignites interior walls.

2. Aging, or field use, appears to reduce the fire resistance of shelter materials.

3. Flammability Methods 5903 and 5905 are limited in their ability to predict overall shelter response to either external or internal fires.

4. The polyurethane foam in shelters manufactured under MIL-S-43869A (GL) appear to possess the most significant resistance to flames when tested by laboratory methods.

XII. ANALYSIS OF THE INTERIOR SMOKE HAZARD

A. SPECTROSCOPIC ANALYSIS OF SMOKE COMPONENTS

Prior tests with MUST Shelters had indicated no potential threat from toxic compounds generated by the combustion of interior components, nor any significant risk due to reduction in visibility by smoke generated within the shelter. However, it became apparent during the interior alcohol spill test within the first Firestone shelter that a potential for both threats existed, since personnel within the shelter, who were observing the test and monitoring internal temperatures, were forced to evacuate within one minute, due to the accumulation of a dense, acrid smoke.

Equipment and technique for evaluating this threat were quickly developed and tests performed within the last shelter studied. Except for the floor of this shelter, Air Cruiser Co. No. 6, equivalent tests in the other shelters were simulated by igniting the surface of a two-foot-diameter section of each of the other manufacturers' products within shelter No. 6.

One pint of isopropyl alcohol was poured onto the tent floor, shelter No. 6, or within a depression formed in the floor simulants, and ignited. Personnel wearing gas masks observed the

generation of smoke and, with pre-evacuated 1000 ml flashes, collected samples at a height above each burning sample where the smoke appeared to be most dense. The collected gasses were later bled into a gas cell with Brewster angle windows and examined semiquantitatively by Laser Raman Spectroscopy (wavelength 488.0 nm). The pressure in the gas cell ranged from 0.5 to 0.8 Pa in different runs.

A preliminary analysis was made with one of the gas samples collected from the simulated burning of a Firestone shelter floor. The flask had been held approximately 60 cm above the floor and directly over the flame. The gasses N_2, O_2, CO_2, and H_2O were readily detected in this sample, but no traces of the gasses HCN, NH_3, CO, and CH_4 were observed. Consequently, these latter gasses were not searched for in the remaining analysis. Gasses from all the remaining tests were collected at heights of either 165 cm or 210 cm above the floor, and analyzed semiquantitatively for N_2, O_2, CO_2, and H_2O.

The results of these analyses are summarized in Table 6, where the numbers given are the Raman peak heights at the cited wave numbers relative to the nitrogen peak height. Nitrogen was used as the internal standard, since it can be assumed that nitrogen molecules are not appreciably produced or depleted during combustion. The data of Table 6 can be interpreted in the following manner. The data for oxygen measured with air collected in the laboratory showed a peak height of 34, while the data for the combustion samples showed no appreciable change in oxygen content at the collection height. In contrast, both the CO_2 and H_2O contents increased significantly. A sample spectra is attached (see Figure 27).

In addition to the Raman spectra cited, additional gas samples were analyzed by infrared techniques and again compared to laboratory air. The spectra obtained in these analyses are shown in Figures 28 to 30. These spectra also show an increased presence of H_2O and CO_2 in the gases collected within the shelter, but no presence of materials normally considered toxic.

TABLE 6

RAMAN SPECTROSCOPIC ANALYSIS OF THE COMBUSTION GASSES

Gasses	Wave Number	Reference Laboratory	Sample Height and Manufacturer					
	cm^{-1}	air	Firestone		Inflated Products Co.		Air Cruisers Co.	
			60 cm	165 cm	165 cm	210 cm	165 cm	165 cm
N_2	2331	100	100	100	100	100	100	100
O_2	1557	34	28	33	34	32	30	34
CO_2	1285	0.23	1.0	0.5	0.4	0.3	1.1	0.8
H_2O	3652	0.73	1.6	1.0	0.9	0.8	2.0	1.6

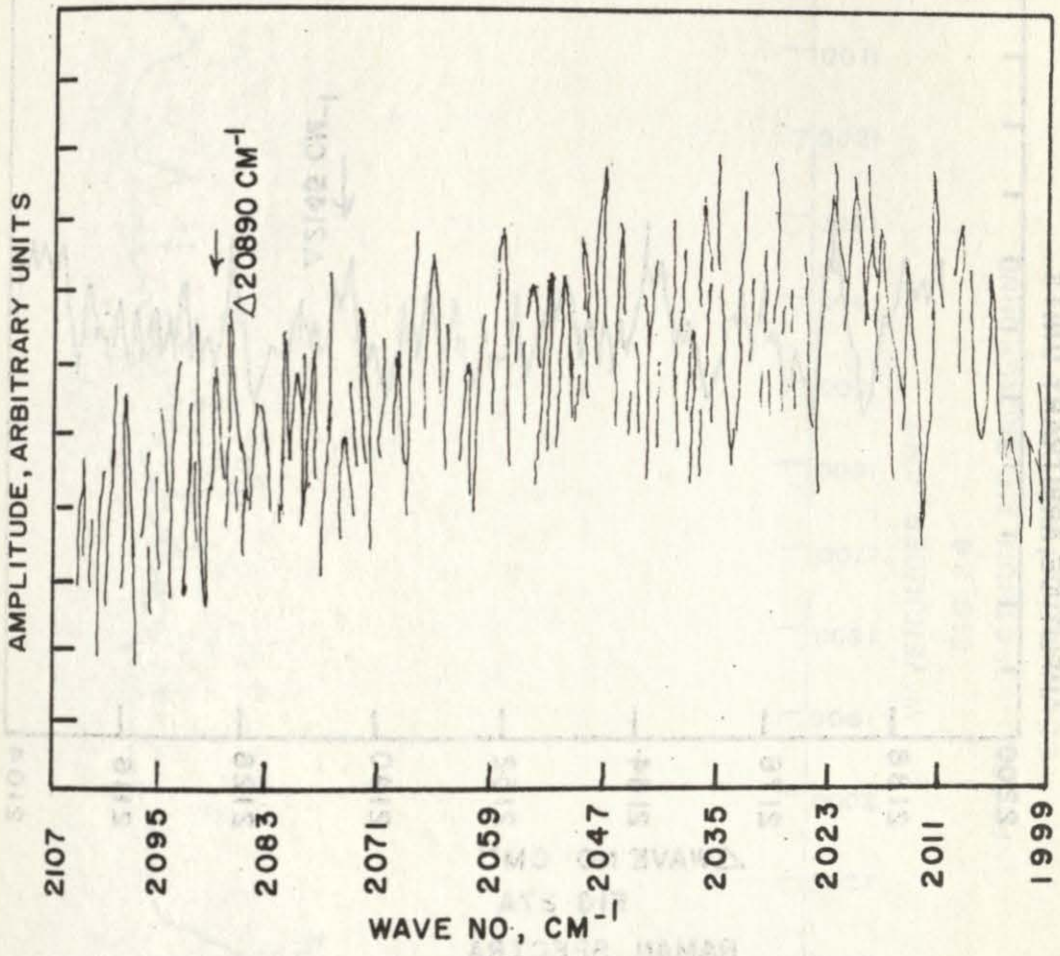


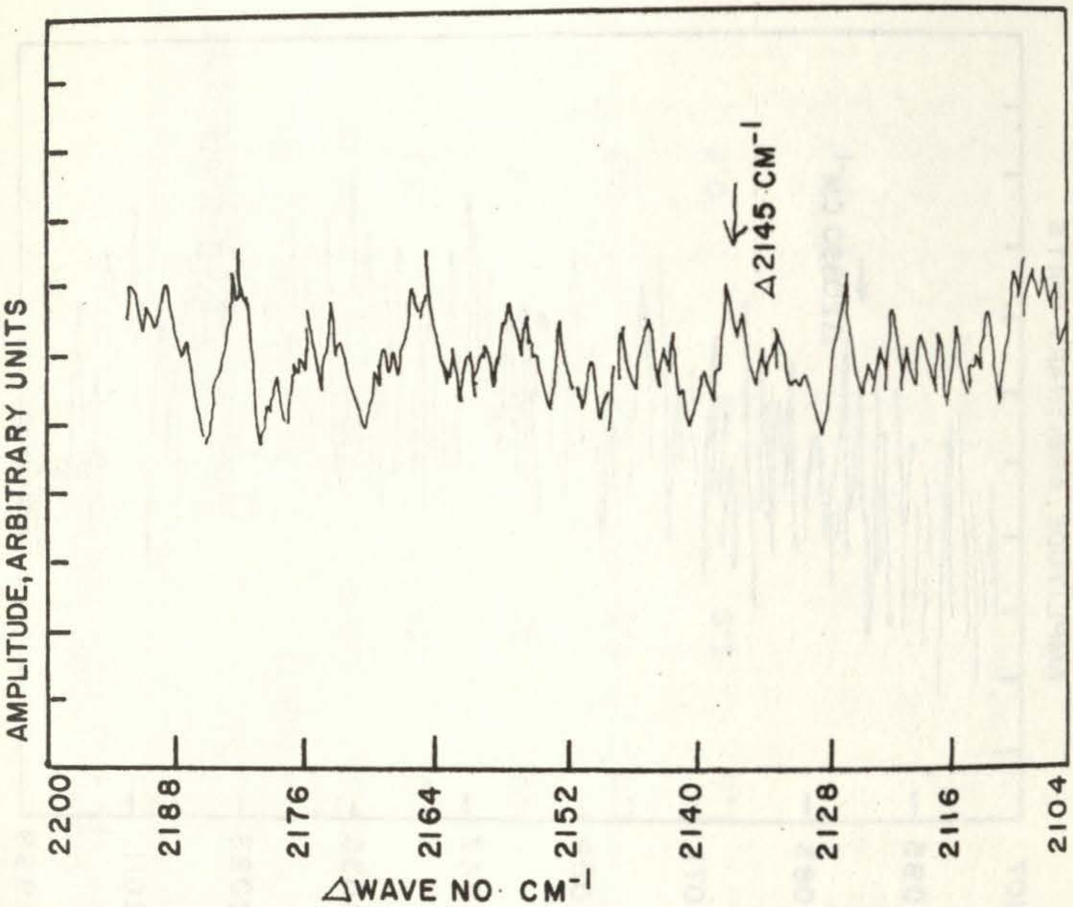
FIG. 27

SCAN RANGE, 2000- 2107 CM^{-1}

NO DETECTABLE HCN, 2089 CM^{-1}

SENSITIVITY, 30 X

RAMAN SPECTRA



FIG·27A

RAMAN SPECTRA

SCAN RANGE, 2104 - 2200 CM^{-1}

NO DETECTABLE CO, 2145 CM^{-1}

SENSITIVITY, 100 X

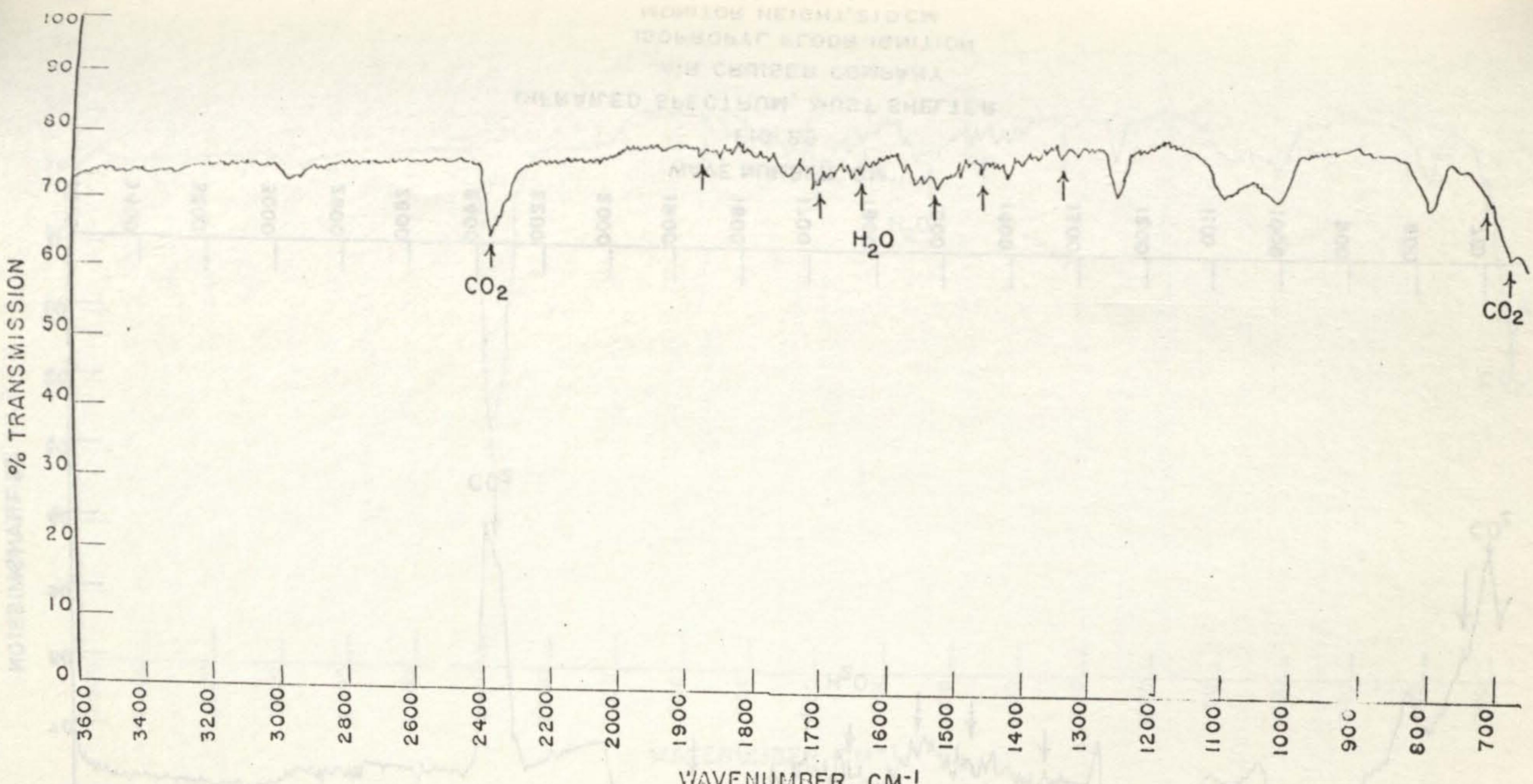


FIG. 28
INFRARED SPECTRUM, AIR BACKGROUND
CELL PATH, 1 METER

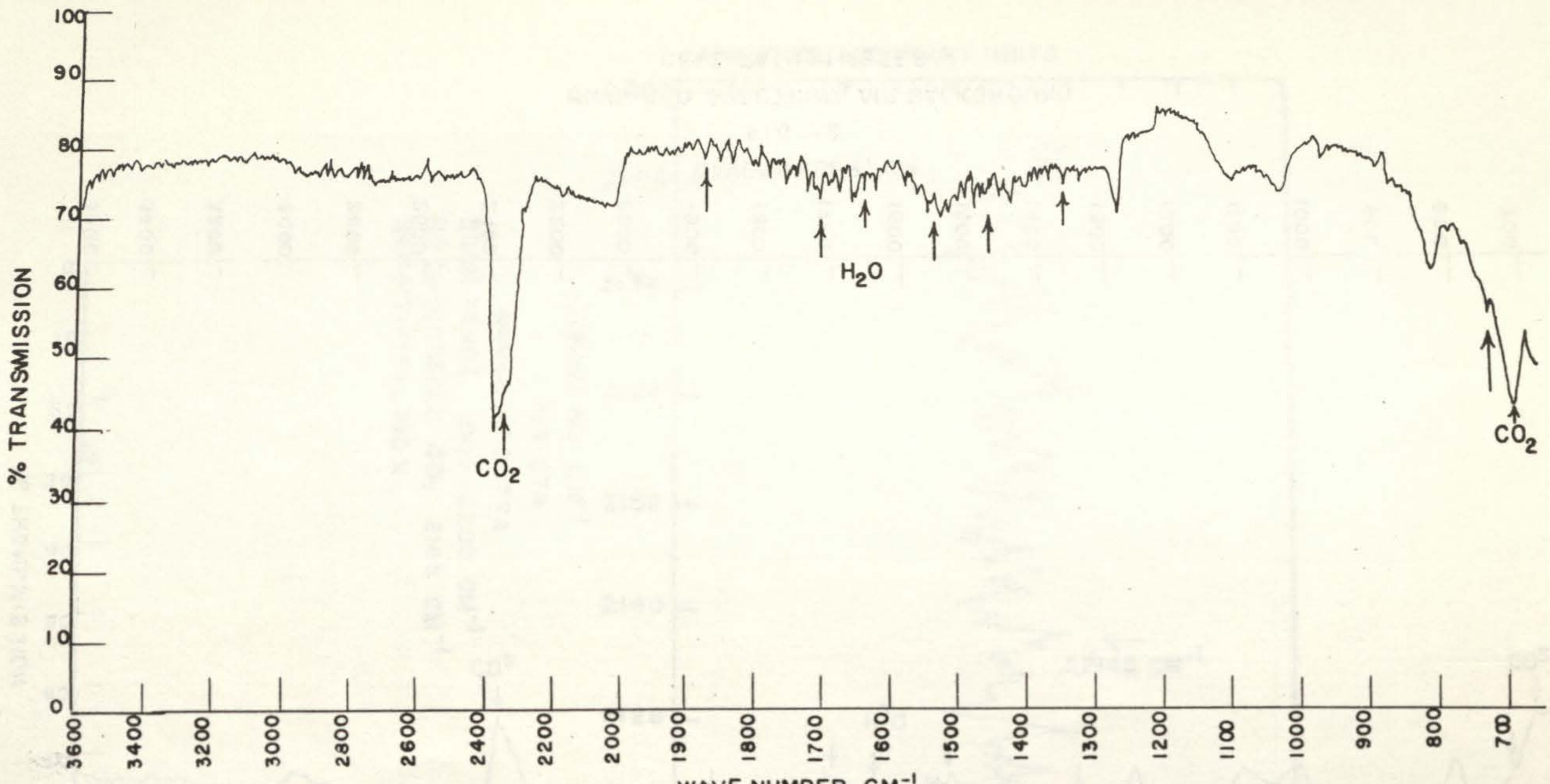


FIG. 29

INFRARED SPECTRUM, MUST SHELTER

AIR CRUISER COMPANY

ISOPROPYL FLOOR IGNITION

MONITOR HEIGHT, 210 CM

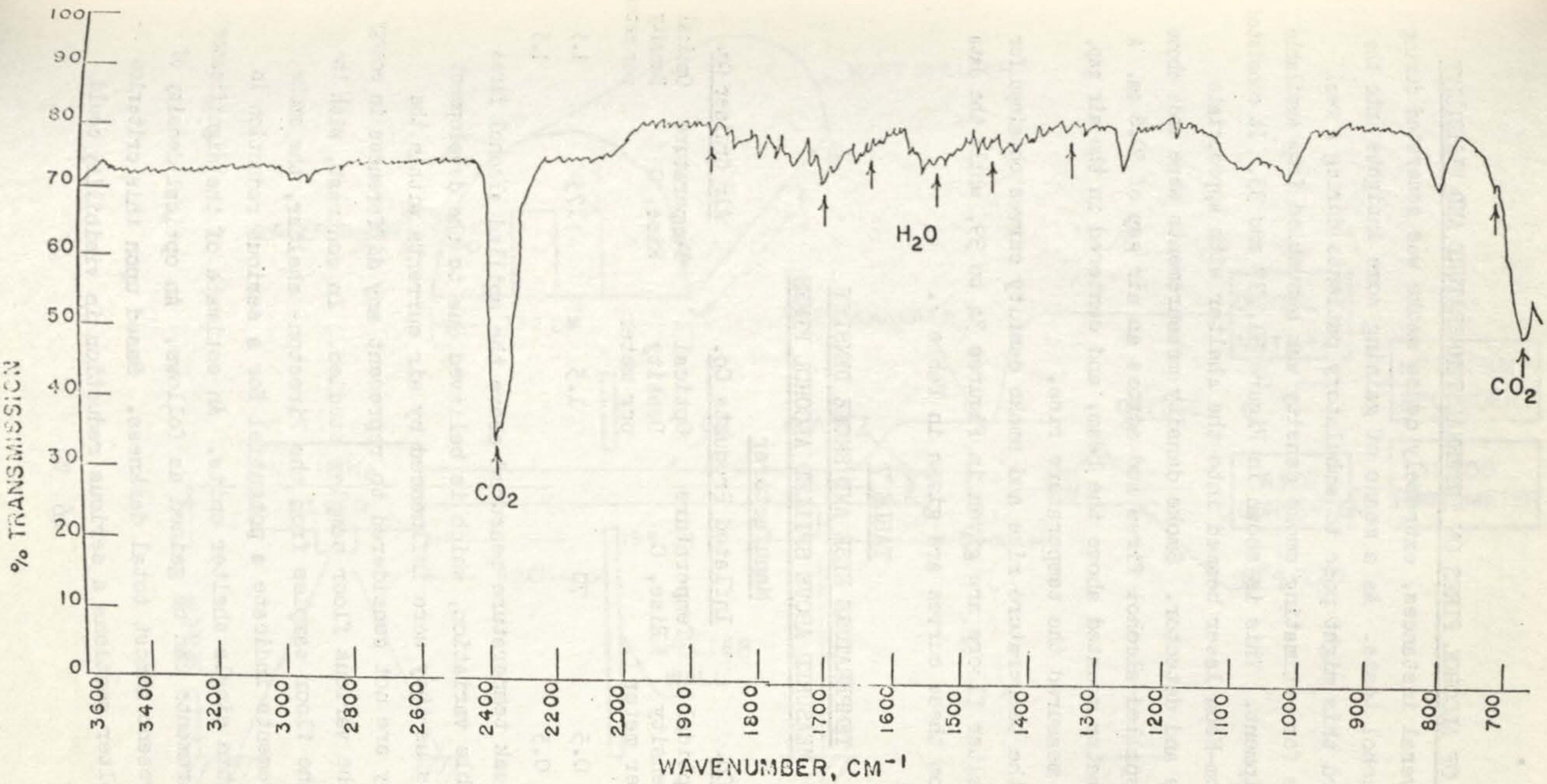


FIG.

INFRA RED SPECTRUM, MUST SHELTER

AIR CRUISER COMPANY

ISOPROPYL FLOOR IGNITION.

MONITOR HEIGHT, 100 CM

B. EFFECT OF ALCOHOL FIRES ON INTERNAL TEMPERATURE AND VISIBILITY

In several instances, extremely dense smoke was generated during the spilled alcohol tests. As a means of gaining some insights into the potential hazard this might pose to ambulatory patients during a real event, a device for estimating smoke density was assembled from available laboratory equipment. This is shown in Figure 31, 32 and 33. It consisted of a 5-mW Helium-Neon laser beamed into the shelter with appropriate optical windows and detector. Smoke density measurements were made above the simulated spilled alcohol fires and across an air gap of 50.8 cm. A digital thermometer mounted above the beam, and centered in the air gap, simultaneously measured the temperature rise.

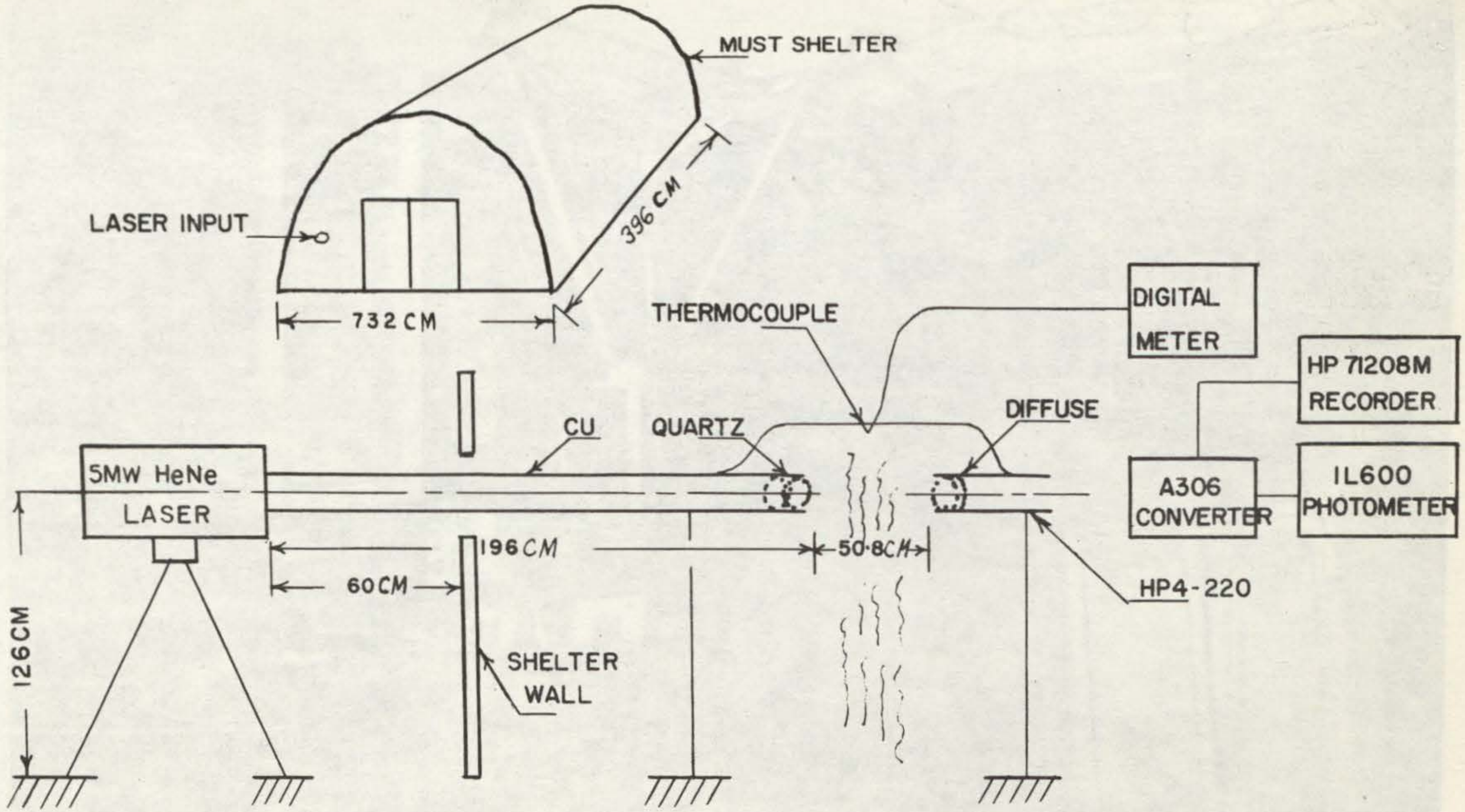
Both the temperature rise and smoke density curves obtained for the various shelter floors are given in Figures 34 to 39, while the data interpreted from these curves are given in Table 7.

TABLE 7

TEMPERATURE RISE AND SMOKE DENSITY MEASURED ABOVE SPILLED ALCOHOL FIRES

Manufacturer					
Firestone Co.		Inflated Products Co.		Air Cruiser Co.	
Temperature Rise, C	Optical Density per meter	Temperature Rise, C	Optical Density per meter	Temperature Rise, C	Optical Density per meter
50	0.5	70	1.5	175	1.5
	0.5				1.5

The peak temperature measured above the spilled alcohol fires show considerable variation, which is believed due to the development of flame plumes as they were influenced by air currents within the shelters. They are not considered to represent any differences in energy generated by the various floor samples studied. In contrast, with the exception of the floor samples from the Firestone shelter, the smoke density measurements indicate a potential for a serious reduction in visibility within single shelter units. An estimate of the significance of these measurements can be gained as follows. An optical density of 3.0 would represent almost total darkness. Based upon this criterion for single shelter sections a serious reduction in visibility could



FIG·31
SCHEMATIC DIAGRAM FOR SMOKE DENSITY
AND TEMPERATURE MEASUREMENTS

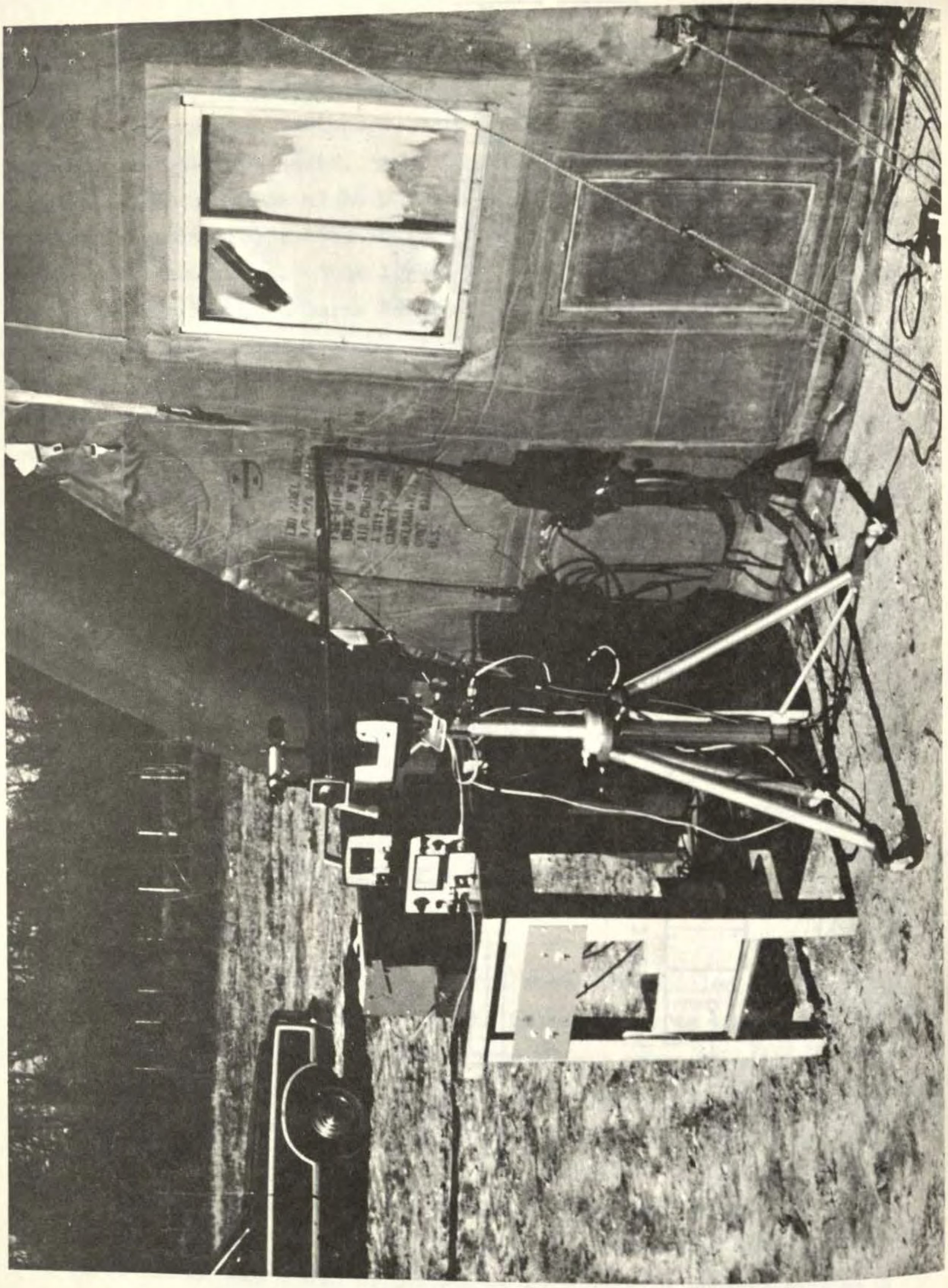


Figure 32. Extra Shelter Setup of Optical and Thermal Apparatus

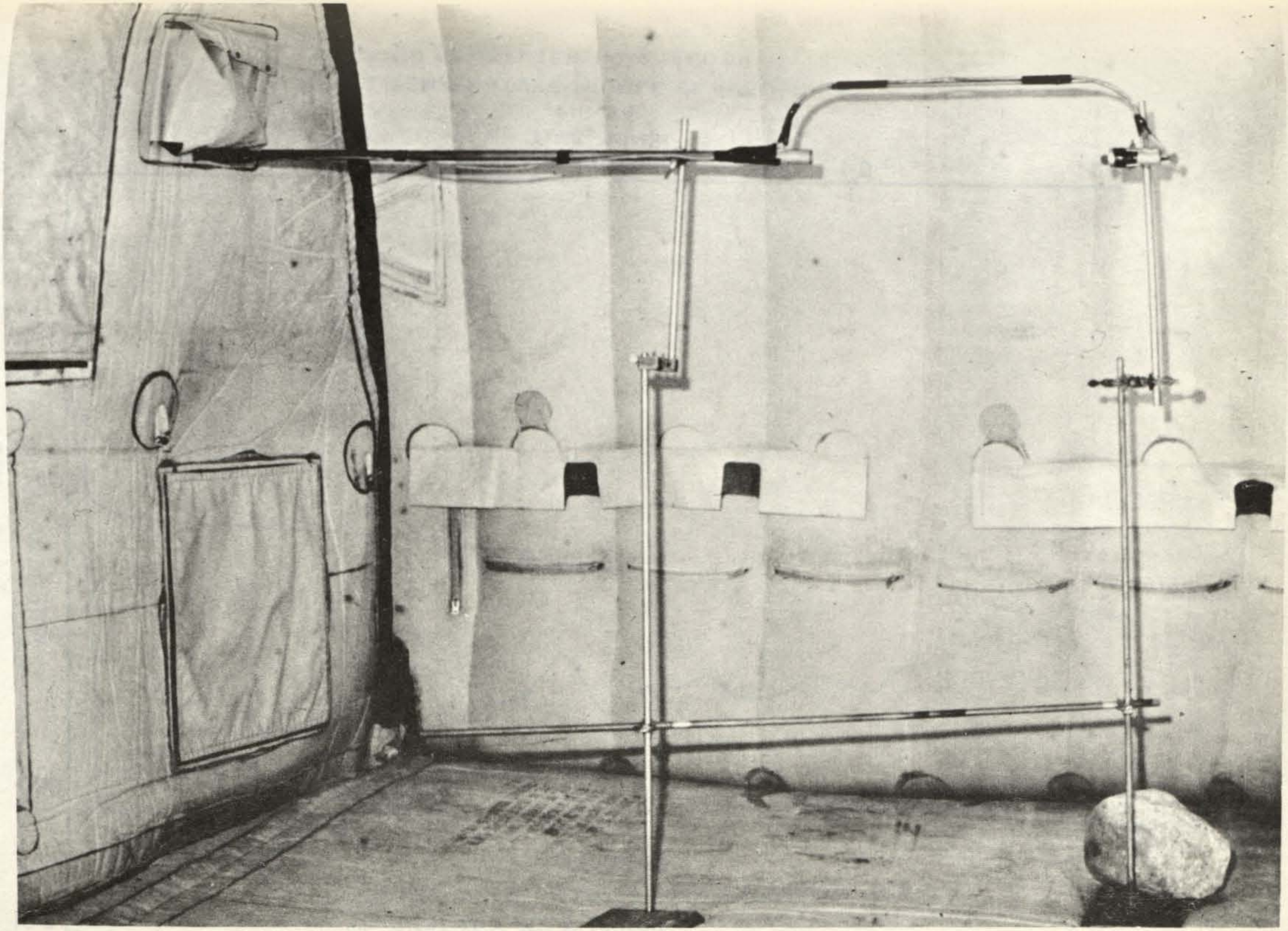
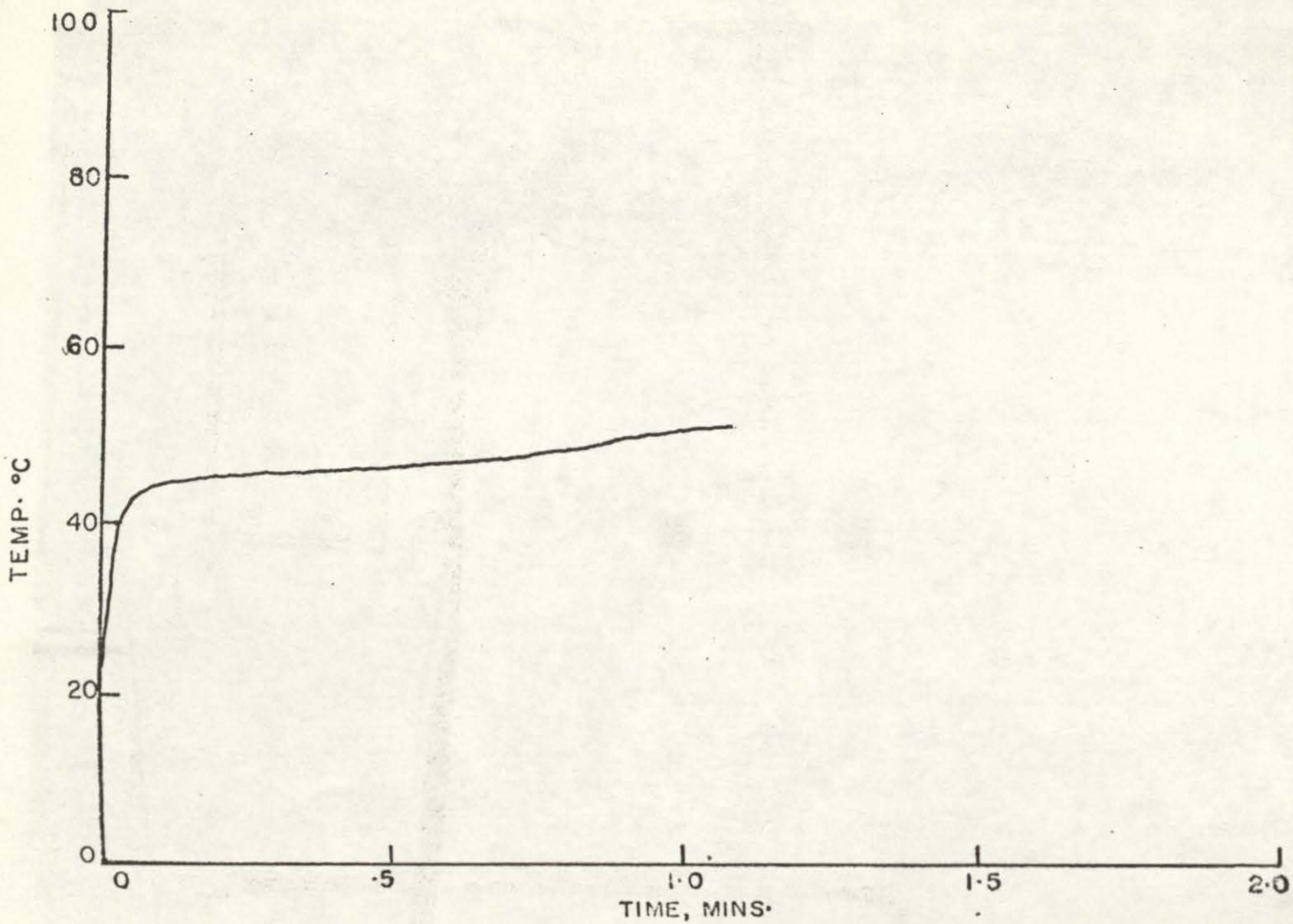
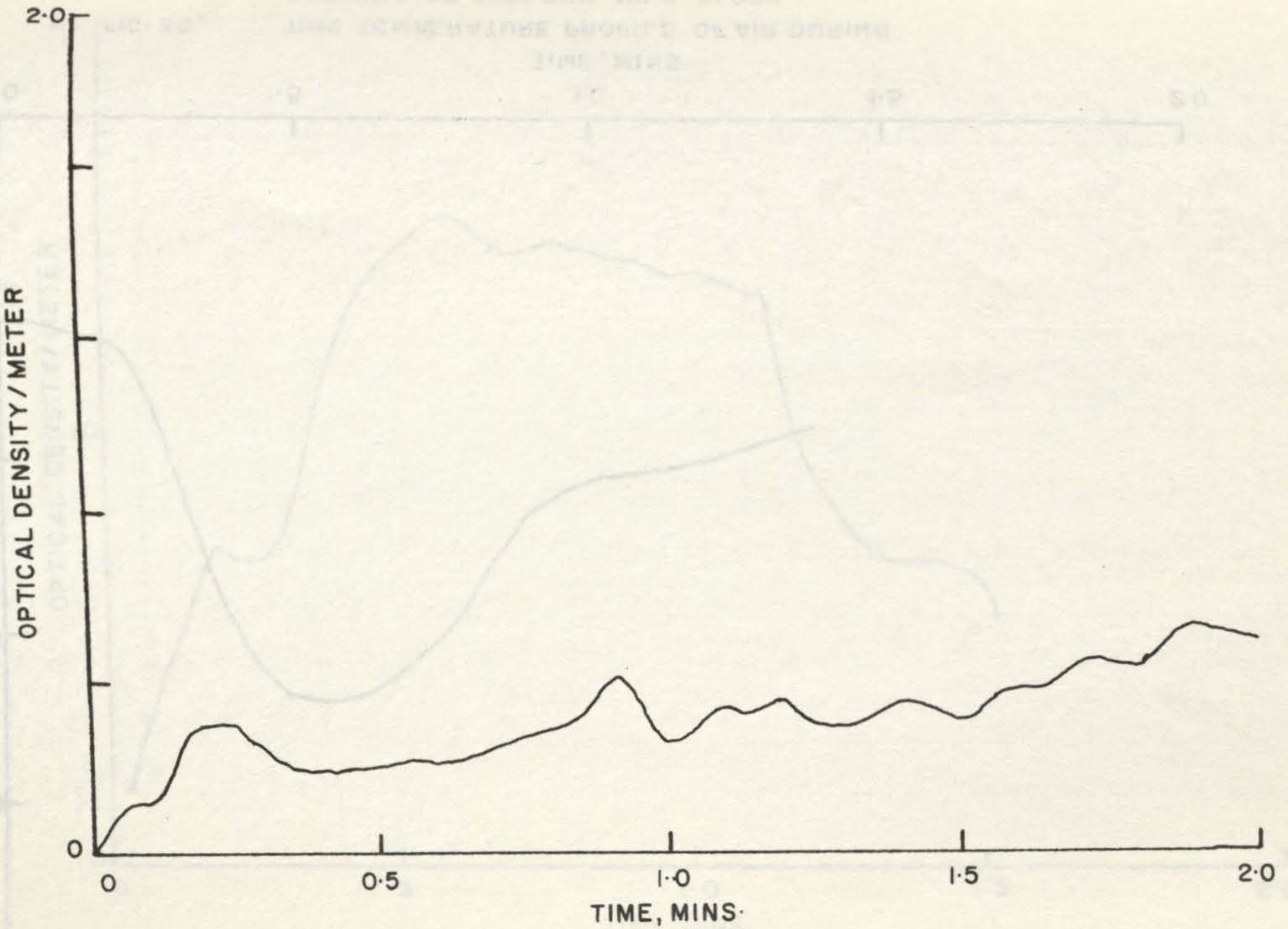


Figure 33. Intrashelter Setup of Optical and Thermal Apparatus

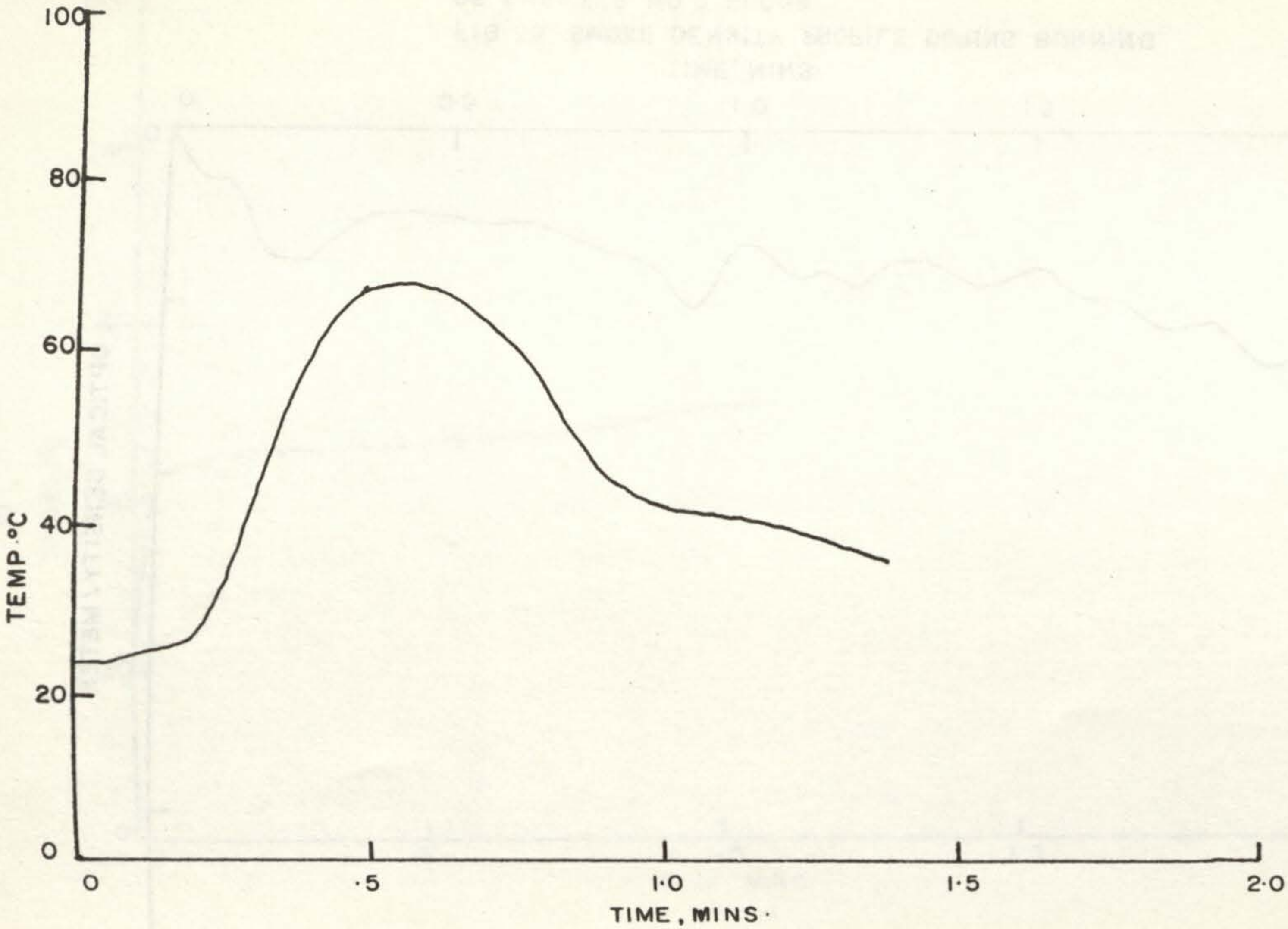


FIG·34

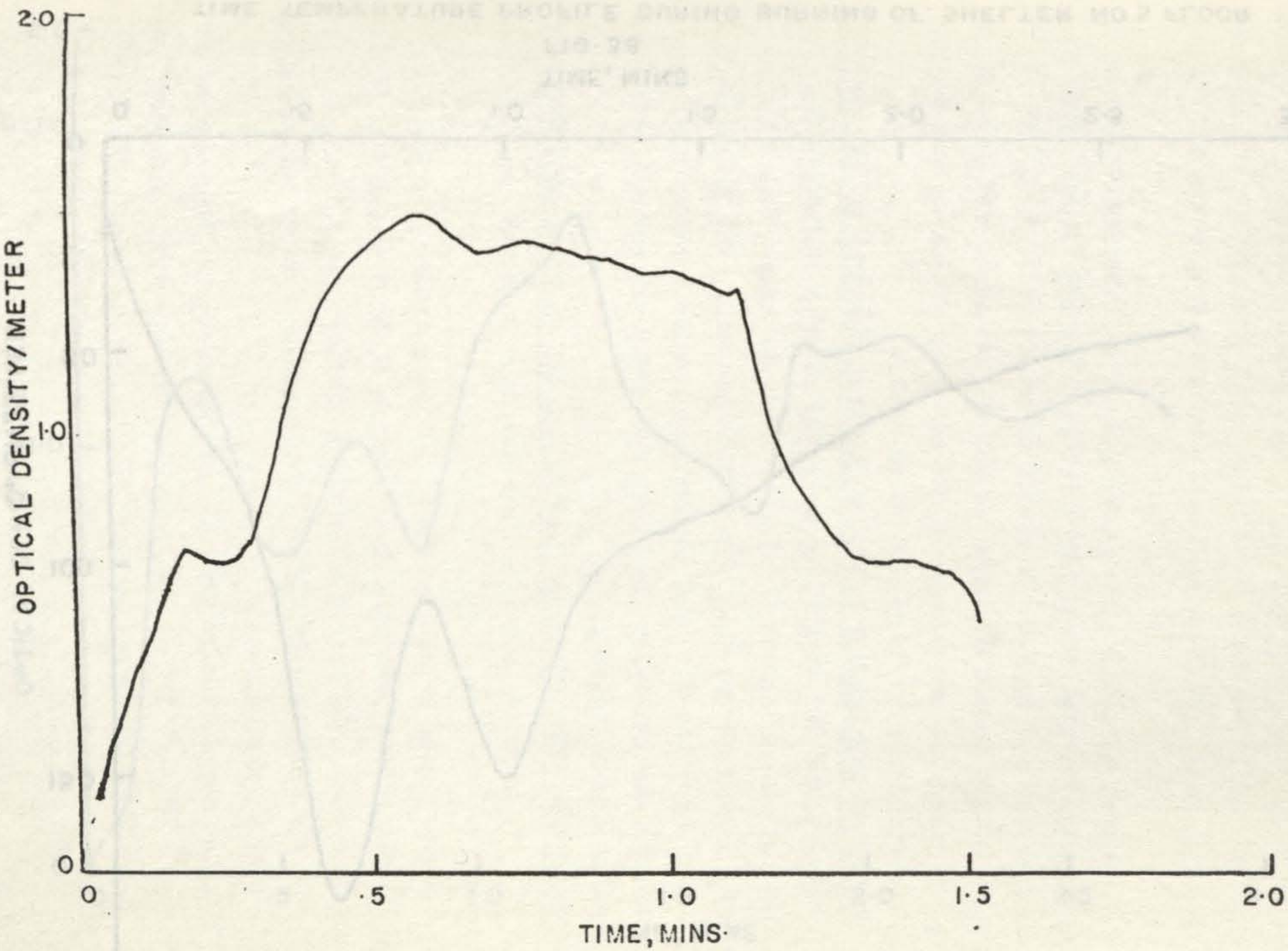
TIME TEMPERATURE PROFILE OF AIR DURING BURNING OF SHELTER NO 2 FLOOR



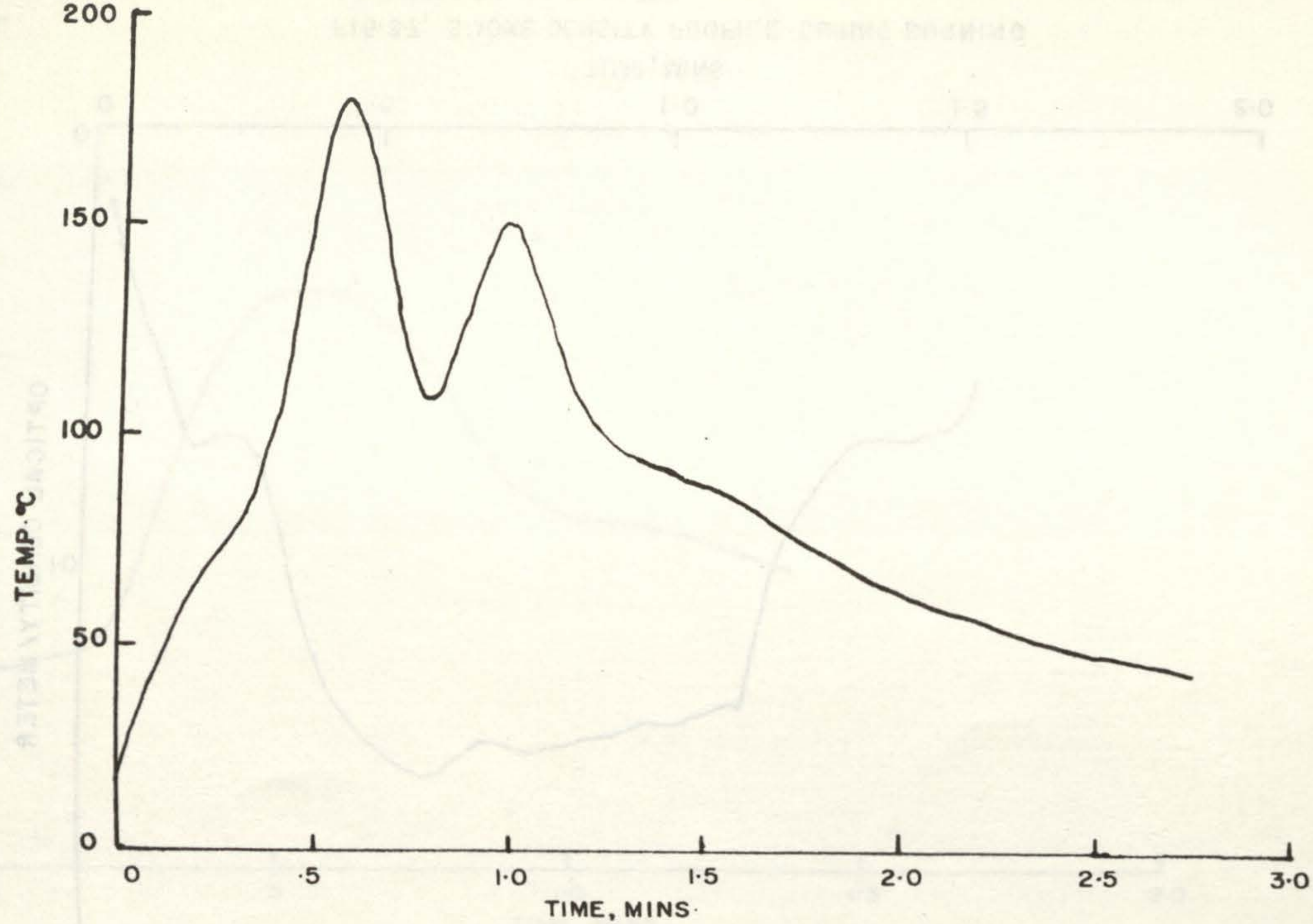
FIG·35, SMOKE DENSITY PROFILE DURING BURNING OF SHELTER NO 2 FLOOR



FIG· 36, TIME TEMRERATURE PROFILE OF AIR DURING BURNING OF SHELTER NO 3 FLOOR



FIG·37, SMOKE DENSITY PROFILE DURING BURNING OF SHELTER NO 3 FLOOR



FIG·38

TIME TEMPERATURE PROFILE DURING BURNING OF. SHELTER NO 5 FLOOR

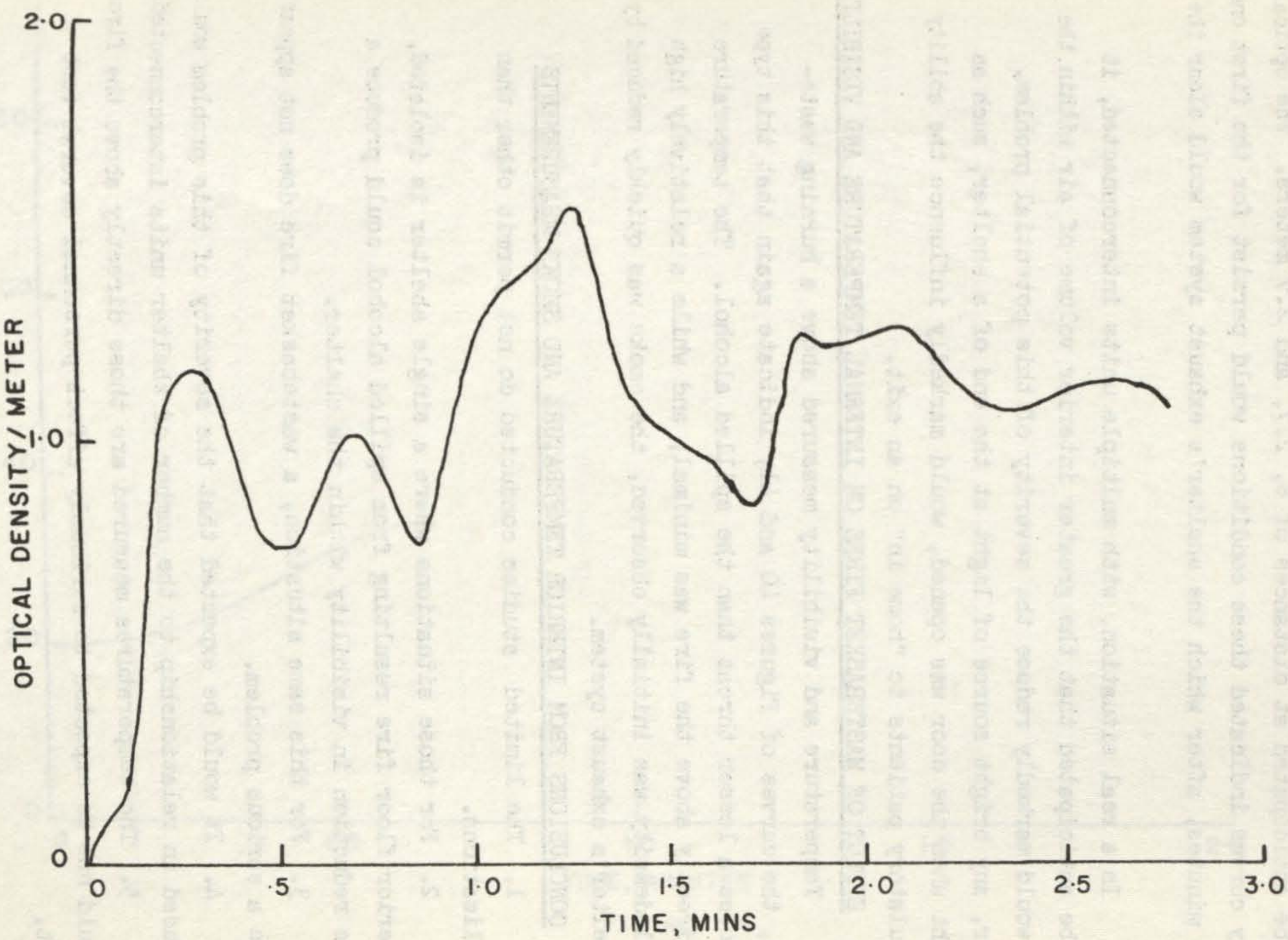


FIG 39, SMOKE DENSITY PROFILE DURING BURNING OF SHELTER NO 5 FLOOR

occur at distances of 6, 2, and 2 meters for the Firestone, Inflated Products, and Air Cruiser Shelters, respectively, while total darkness could be anticipated at distances of 8, 2.7, and 2.7 meters. The optical density curves indicated these conditions would persist for the first one to two minutes, after which the shelter's exhaust system would clear the air.

In a real situation, with multiple units interconnected, it would be anticipated that the greater interior volume of air within the units would markedly reduce the severity of this potential problem. Further, any bright source of light at the end of a shelter, such as sunlight when the door was opened, would markedly influence the ability of ambulatory patients to "home in" on an exit.

C. EFFECT OF WASTEBASKET FIRES ON INTERNAL TEMPERATURE AND VISIBILITY

Temperature and visibility measured above a burning wastebasket, the curves of Figures 40 and 41, indicate again that this type fire poses a lesser threat than the spilled alcohol. The temperature rise directly above the fire was minimal, and while a relatively high optical density was initially observed, the smoke was quickly reduced by the shelter's exhaust system.

XIII. CONCLUSIONS FROM INTERIOR TEMPERATURE AND SMOKE MEASUREMENTS

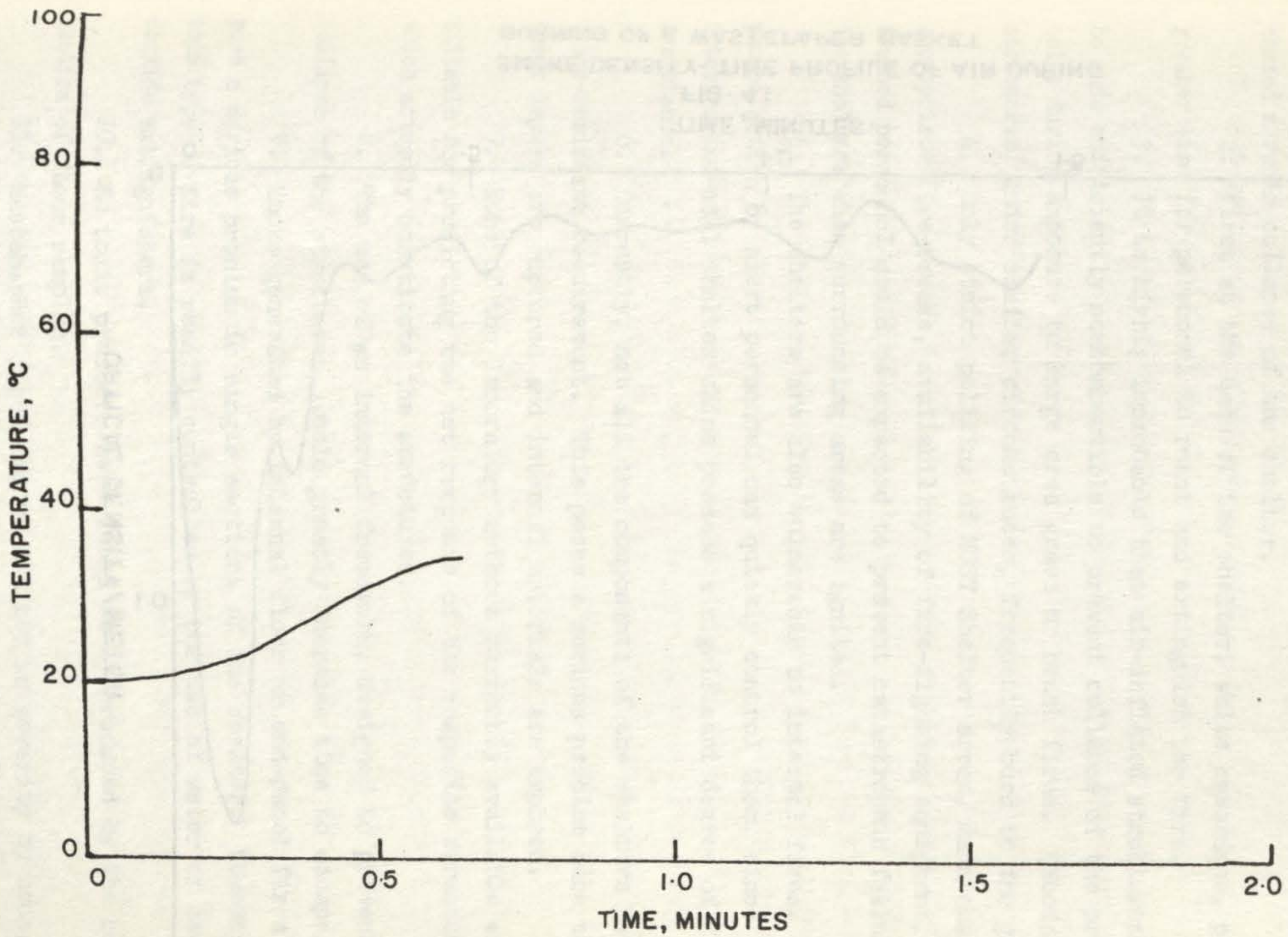
1. The limited studies conducted do not permit other than generalizations.

2. For those situations where a single shelter is isolated, an interior floor fire resulting from spilled alcohol could produce a serious reduction in visibility within the shelter.

3. For this same situation, a wastebasket fire does not appear to pose a serious problem.

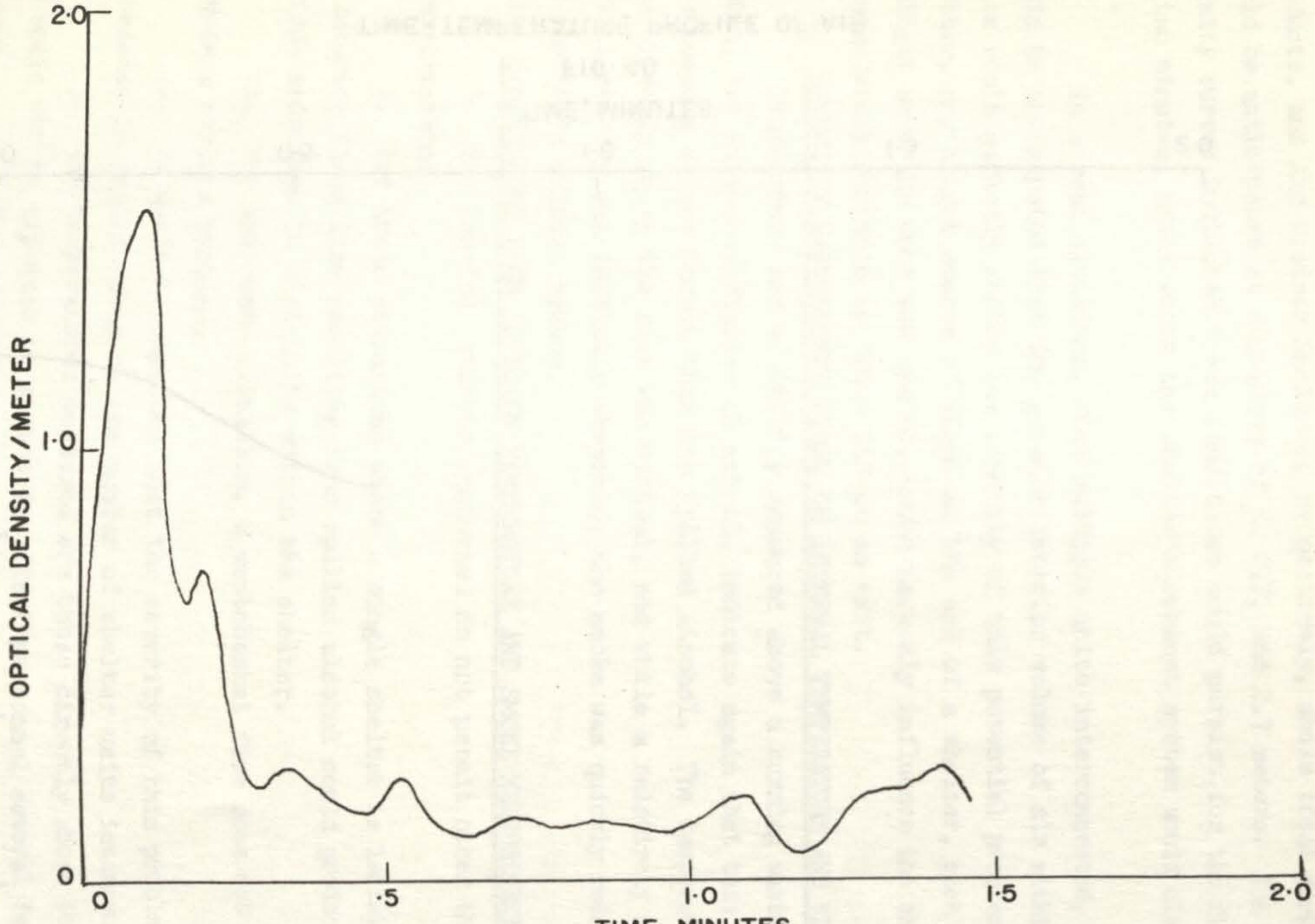
4. It would be expected that the severity of this problem would be reduced in relationship to the number of shelter units interconnected.

5. The temperatures measured are those directly above the fires, and would not be expected to seriously affect personnel several feet distant.



FIG· 40

TIME-TEMPERATURE PROFILE OF AIR
DURING BURNING OF A WASTEPAPER BASKET



FIG· 41

SMOKE DENSITY- TIME PROFILE OF AIR DURING BURNING OF A WASTEPAPER BASKET

XIV. GENERAL CONCLUSIONS

1. The MUST Shelters tested were found to be vulnerable to external fires, particularly those fires along the inflated sides which caused a rapid collapse of the shelter.

2. Fires at the ends of the shelter, while hazardous, permit greater time for personnel to react and extinguish the fire.

3. It is highly improbable that air-inflated structures can be made sufficiently noncombustible to prevent collapse of the pressurized cells during exposure to large area grass or brush fires. (Wooden structures, under similar circumstances, frequently burn to the ground.)

4. Only strict policing of MUST Shelter areas, maintenance of appropriate fire-breaks, availability of fire-fighting equipment, and trained personnel could be expected to prevent catastrophic failure of the shelters when surrounding areas are ignited.

5. The shelters are also vulnerable to internal fires, but prompt action by alert personnel can quickly control them, since interior end-wall shelter skins possess a significant degree of flame-resistance.

6. Currently, not all the components of the shelters have a flame-resistant requirement. This poses a serious problem once the outer layers are ruptured and internal materials are exposed.

7. None of the laboratory methods currently available are suitable for predicting the net response of the composite structures which actually constitute the structures.

8. The use of an internal framework, designed to prevent total collapse of the structures, would greatly increase time to escape.

9. Smoke generated by internal floor or end-panel fires can pose a serious problem in single sections of the shelter. However, this type of fire is readily controlled by the use of water or carbon dioxide extinguishers.

10. No toxic products were found to be produced by the combustion of floor samples.

11. Wastebasket fires can be limited in severity by housekeeping and insuring that wastebaskets are not placed in close proximity to any wall.

12. Although the laboratory tests indicate some differences in the response of specific components, the field studies indicate that the time to ignite and collapse did not differ significantly between manufacturers.

13. None of the polyurethane foam tested possessed a desirable degree of flame-resistance.

14. Test procedures used to measure potential smoke hazards and evolution of potentially toxic compounds need to be refined. Additionally, a laboratory method is needed for measuring the net response of simulated end panels and side walls to appropriate energy inputs.

15. In general, the existing shelters are vulnerable to fire, both external and internal. However, they appear to possess a degree of flame-resistance, and prompt reaction by permanent staff members to small fires would markedly reduce the fire-hazard.

XV. RECOMMENDATIONS

1. In addition to a standby fire truck and crew maintained in the MUST area, it is recommended that hand-operated water extinguishers, as well as carbon dioxide extinguishers, be maintained within the shelters. Additionally, permanent staff members should be trained, under field conditions, to control internal alcohol spill fires and wastebasket fires. They should also be alerted to the necessity for prompt reaction with hand-held equipment in controlling small external fires.

2. The MUST shelter area should be cleared of combustible debris as required by regulation.

3. It is conceivable that with large area brush fires sufficient radiant energy could be imposed on the shelters to cause collapse of the pressurized cells prior to actual contact with flames. This aspect of the problem may ultimately require "fire-modeling" studies. Initially, it is recommended that the response of shelter simulants to appropriate radiant energy loads be determined.

4. All components of the shelter should be made flame-resistant.

5. The inspection and quality-control procedures used in the manufacture of the polyurethane foam need "tightening" to insure that the foam possesses the required degree of flame-resistance.

6. Investigate the feasibility of utilizing inherently non-combustible insulating material in lieu of the polyurethane foam.

7. Investigate the feasibility of using high temperature fabrics as the outer skin of the inflated tubes.

8. Utilize the internal arch support frame (MIL-S-43766 (GL)) which was designed and intended to furnish support of shelter sections when there is no internal pressure in the inflated tubes, as required by regulation, to prevent total collapse of the shelters when pressurized cells are ruptured.

9. Develop test methods for measuring the response of simulated shelter sections to the various fire hazards, and refine techniques for estimating the density and composition of smoke evolved during internal fires.